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Seed Quality and Variety Preferences Amongst Potato Farmers in North-Western Kenya: Lessons for the Adoption of New Varieties

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Abstract

Potato (*Solanum tuberosum* L.) is an important commercialised food crop in Kenya. Recently, Kenya has realised a huge increase in the number of formally released potato varieties. The performance of these varieties is not clear and their adoption across various growing environments is low. This study explored how availability, access, quality and systems of seed and storability and market demand of potatoes influence farmers' decisions on choice of varieties they grow and how they select seed for planting in the different seasons. Focus group discussions (83 farmers) and a household survey (225 farmers) were conducted in three major potato growing areas (Lelan, Saboti and Kaptama) in north-western Kenya. Results showed that farmers mainly used farm-saved seed and only 4.9% had used certified seed, while 71% indicated that certified seed was not available locally. Almost all farmers ensured they used healthy seed by visually examining the seed tubers while most farmers also examined the health of the crop in the field before harvest. Farmers renewed their seed depending on the number of cycles used, infection, decline in yield and availability of clean seed. Seed was usually renewed for up to after 5 years of recycling, and generally involved the varieties Shangi, Kabale and Arka. Farmers ranked five variety traits: tuber yield, disease resistance, market demand, early maturity and storability as most important in the choice of a variety. Farmers understood the importance of dormancy and had methods for managing dormancy, but their knowledge was biased to the few varieties they had, particularly Shangi, the predominant variety in the market. Despite agronomic attributes, market demand featured as a primary determinant of variety choice amongst farmers. The findings from this paper can guide use of seed, adoption of new varieties and future breeding of potato varieties for Kenya.

Keywords Seed health · Certified seed · Variety choice · Dormancy · Market demand · *Solanum tuberosum*

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Introduction

Potato (*Solanum tuberosum* L.) is an important food and cash crop, which does well in cool sub-tropical and tropical highlands (Haverkort and Struik 2015). In the Kenyan highlands, potato is commonly grown twice a year, during the long (March/April-July/August) and short (September/October-November/December) rainy seasons (Gildemacher et al. 2009), with drought stress occasionally experienced in the latter season. Potato plays a major role in national food and nutrition security (Kaguongo et al. 2010). However, its production is beset by both biotic and abiotic stresses and by limited availability of quality seed of adapted and desirable varieties (Gildemacher et al. 2009; Muthoni 2013). Although numerous varieties have been tested and released in the recent past (Janssens et al. 2013; Komen et al. 2017), the performance of these varieties and their adoption across various growing environments is not clear. Through public-private-partnerships embraced by the Kenyan government in recent years, Kenya has realised a huge increase in the number of formally released varieties (Lunga'ho and Schulte-Geldermann 2016; Komen et al. 2017); however, some of these varieties have not yet been widely distributed (Lunga'ho and Schulte-Geldermann 2016). Nuijten et al. (2015) recommended involvement of traders, supermarkets and other value chain players in early phases of cultivar testing for optimisation of cultivar introductions. To successfully introduce new varieties into farming practices, it is also important to develop an understanding of farmers' preferences and practices (Kolech et al. 2017).

Focus group discussions and a household survey were conducted with potato growers in three major potato growing areas in north-western Kenya to assess seed access and varieties grown, farmers' trait preferences and dormancy qualities. This paper examines the perceptions, knowledge and understanding that potato farmers have about different varieties and the considerations that influence their variety choices. It explores the relationship between access to quality seed and varieties in light of seed systems, and how issues of availability and access to healthy seed, market demand and agronomic factors influence variety choice.

Understanding dormancy and sprouting characteristics in seed potato is crucial and this study investigates the trait association with variety and seed origin. Dormancy is the physiological state of the tubers in which tubers do not sprout even when placed in ideal germination conditions (Struik and Wiersema 1999; Caldiz et al. 2001; Sonnewald and Sonnewald 2013; Mani 2014). The dormancy period varies from 2 to 4 months (Kwambai et al. 2023), depending on genotype and pre- and post-harvest conditions. On the other hand, physiological age refers to the state of the seed tuber at any time, determined by genotype, chronological age and environmental conditions from tuber initiation until new plant emergence (Caldiz 2009) or the stage of development of a tuber, which is modified progressively by increasing chronological age, depending on growth history and storage conditions (Struik and Wiersema 1999).

The status of tuber dormancy and/or physiological ageing can significantly affect time and rate of emergence. Moreover, the double cropping of potato in Kenya demands extra attention to seed tuber behaviour. Therefore, we also examined farmers' understanding of seed quality (degree of sprouting, rotting, emergence/vigour)

and how they assign different varieties to different seasons. Farmers' mitigation approaches to dormancy management were recorded.

The findings from this paper can guide use of quality seed and the introduction and adoption of new varieties that may be suitable for different parts of Kenya. Several hypotheses were developed to explore the relationship between farmers' knowledge about and preferences for different varieties, seed qualities, and seed and crop management. Such knowledge has the potential to considerably guide training objectives of potato farmer extension projects and variety development for Kenya.

The hypotheses were:

1. Farmers make rational decisions on variety choice based on availability and access to healthy seed, agronomic resilience and productivity, and ware potato market demand.
2. Understanding of dormancy and physiological seed quality by farmers is masked by variety choice.
3. Variety choice is influenced by ware quality and storability.

Materials and Methods

Study Area and Farmer Descriptions

Eighty-three representative, active potato growers, comprising men and women, were selected across each study site from a list prepared by the agricultural extension personnel and key informant farmers for a focus group discussion (FGD) in three study sites in March 2018. The study sites were Lelan ward in Marakwet West Sub-County, Elgeyo Marakwet County, Saboti ward in Saboti Sub-County, Trans Nzoia County and Kaptama ward in Mt. Elgon Sub-County, Bungoma County. The study sites were selected purposively from strata based on the high intensity of potato production, active potato growing and the different altitudes in the three sites, and their relative proximity for efficient resource use during the survey. The FGDs at each site were composed of three to four discussion groups of farmers with participants placed into male or female groups of five to eleven participants. The FGDs provided baseline information on potato practices on varieties, seed and seed systems, dormancy and physiological quality and storage which informed the design of the in-depth household survey that followed. During the FGDs, a checklist (not exclusive) was used as a guide to capture data. Participants drew a list of preference traits, which were discussed in each group and subjected to pairwise ranking by comparing trait options and ranking through consensus as in Kwambai et al. (2022). The rankings were harmonised by assessing the traits and the number of times they were ranked by each gender-group and a subjective overall rank awarded in the same order for each gender. A radar chart in Microsoft Excel was constructed for purposes of interpretation (Ghebreagziabiher et al. 2022) of the ranking by gender. The data from the FGDs were summarised using descriptive statistics (frequencies, means and percentages) in the Microsoft Excel computer package.

A household survey was conducted between July and September 2019 using a semi-structured questionnaire (Supplementary Materials 1 and 2) with the aid of Open Data Kit (ODK) using smart phones or tablets (Nbendah et al. 2018). In this paper, some parts of the questionnaire are addressed based on the hypotheses mentioned above while the remaining parts have been addressed in Kwambai et al. (2022). The household survey was carried out in the same wards where the FGDs were conducted. Also, the study sites were selected purposively as for the FGDs above. The distribution of the gender of the participants for the FGDs and the household survey respondents are shown in (Table 1).

The survey was conducted with the assistance of five enumerators at each site. The enumerators were trained at each site after which they pre-tested the questionnaire on a small pilot sample of potato farmers in parts of the target areas prior to the actual survey. The interviews were conducted with a total of 225 respondents, comprising more male (61.8%) than female (38.2%) farmers across the study areas (Table 1). The respondents comprised of 66, 75 and 84 potato farmers in Saboti, Kaptama and Lelan wards, which fell within mean altitudes of 2842, 2223 and 2171 m above sea level, respectively (Table 1). The respondents were selected at random along defined routes across major potato growing areas in each ward but at least three or four farms apart depending on the intensity of potato growing. All respondents selected had grown potato in at least one of the previous two (long and short 2018) rainy seasons. The respondent at each household was the household head, spouse or an alternative member of the household who was active in potato cultivation. Households which could not be interviewed for one reason or another were skipped, and a third or fourth household was interviewed to ensure wider coverage of the ward. Locations of households interviewed are indicated in Fig. 1. Besides data collected on the questionnaire, additional notes were taken on issues raised by respondents and photographs were taken where appropriate. Questionnaire data collected were cleaned and then submitted to Kenya Agricultural and Livestock Research Organization (KALRO) headquarters, where the data were assembled together in Microsoft Excel and sent back to the principal investigator for analysis. The data were then further

Table 1 Distribution of farmer focus group discussion participants and household survey respondents by gender in three study sites (wards) in north-western Kenya

Ward	County	Male	Female	Total
Focus group discussion				
Kaptama	Bungoma	16 (61.5%)	10 (38.5%)	26
Saboti	Tran Nzoia	21 (67.7%)	10 (32.3%)	31
Lelan	Elgeyo Marakwet	18 (69.2%)	8 (30.8%)	26
Total		55 (66.3%)	28 (33.7%)	83
Household survey				
Kaptama	Bungoma	48 (64.0%)	27 (36.0%)	75
Saboti	Tran Nzoia	42 (63.6%)	24 (36.4%)	66
Lelan	Elgeyo Marakwet	49 (58.3%)	35 (41.7%)	84
Total		139 (61.8%)	86 (38.2%)	225

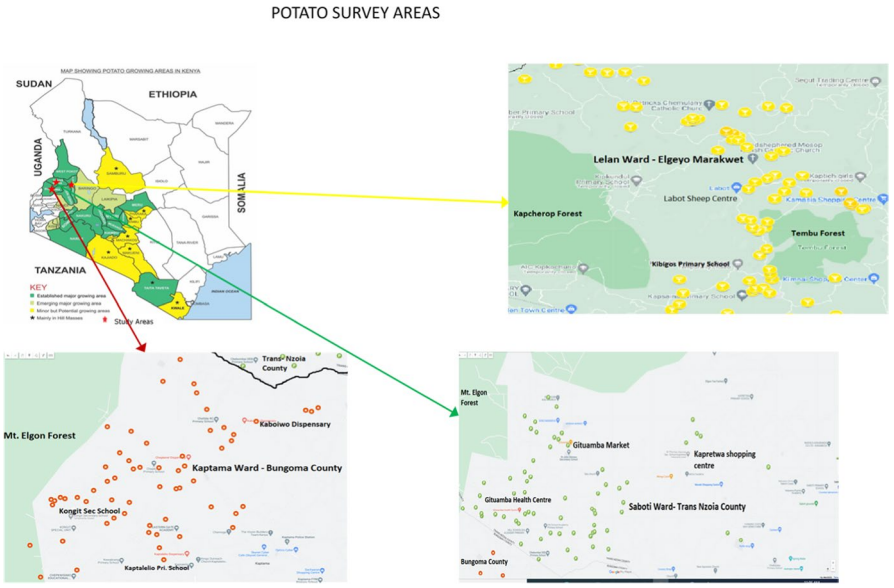

Fig. 1 Study survey sites in Kaptama (2100-2300 m), Saboti (1803–2354 m) and Lelan (2641–3061 m above sea level) and households interviewed (From Kwambai et al. 2022)

cleaned and analysed using the statistical software R (R Core Team 2019). The analysis was achieved through use of cross-tabulations, frequencies, ranking and correlation analysis. The household survey respondents gave incomplete rankings for some of the data as with agronomic resilience and productivity, and to overcome this challenge the most frequently ranked options were extracted and responses from farmers who ranked these options completely were analysed.

Also, some data and figures were processed in Microsoft Excel. In addition, triangulation of the statistical data was done with qualitative data from focus groups, observations and notes taken during the household survey.

Results

The results are presented in response to the hypotheses outlined earlier. One of the challenges in testing the hypotheses was that one variety (Shangi) was the dominant variety grown amongst the sample of farmers surveyed. As a result, the potential of the dataset to evaluate farmers' understanding of potato varieties was mainly limited to Shangi, Arka, Kabale and previously grown varieties through recall. The study findings suggest that farmers do understand dormancy and physiological age in seed potato, but this was often masked by practical factors (variety preferences and their access). The results are presented under the guiding hypotheses below.

Hypothesis 1: Farmers make rational decisions on variety choice based on availability and access to healthy seed, agronomic resilience and productivity, and ware potato market demand

Availability of, and access to healthy seed emerged as a critical determinant of farmers' decisions on variety choice, supported by agronomic traits and marketability of the variety. Farmers grew preferred varieties based on the availability and access of seed at planting time. The seed used was mainly from the informal seed system (home saved, neighbours' or market sourced seed). Only 5% of the household respondents had planted certified seed potato in the previous 5 years. Approximately 96% of farmers use informal seed (Fintrac 2015). The farmers who had used certified seed were motivated to get high yields (91%) and to avoid diseases (55%). The main reasons for not using certified seed potato were that the certified seeds were not available locally, they were expensive, farmers were not aware of sources of certified seed and some farmers were not aware of certified seed (Table 2).

During the household survey, 71% of the respondents indicated that they actively searched for 'healthy seed' of their preferred variety(ies) across study sites with Kaptama having a higher percentage (36.2%) followed by Lelan (33.8%) and then Saboti (30%) (Supplementary Material 3). Respondents used different criteria options to ensure the seed they acquired for planting was healthy (Table 3). Most (92.4%) farmers examined the seed tubers to ensure that they had no signs of insect pests or diseases. The second criterion was visiting and examining the health of the crop in the field before harvesting, followed by trusting the seed grower/supplier.

When asked the options they would consider in case they (household respondents) did not find healthy seed of their preferred variety when they wanted to plant their potatoes, 60.9% indicated that they would plant seed they already had, 57.8% would plant another crop instead, 40.0% would buy healthy seed of a different variety, while 8.9% would purchase seed of their preferred variety regardless of health status of that seed (Table 4). Survey respondents were asked to rank the criteria on which they renew seed of their preferred variety(ies) over time. The percentage of respondents in each area who ranked each criterion amongst their top 2 reasons for renewing seed are shown in Table 5. Most respondents indicated decline in yields as the number one reason for renewing seed, followed by when seed was infected with disease(s) and least when certified seed was available.

Household respondents indicated that they renewed or replaced seed from once a year to once in more than five years (Table 6). This implied that some farmers

Table 2 Reasons given by household respondents for not planting certified seed potato

Reason for not planting certified seed potato	Listed in top 3 reasons
Not available ($N = 225$)	152 (59.6%)
Expensive ($N = 225$)	79 (35.1%)
Not aware of source of certified seed ($N = 225$)	54 (24.0%)
Not aware of certified seed ($N = 225$)	42 (18.7%)

Table 3 Criteria farmers used to ensure the seed variety they acquired for planting was healthy

Criteria of choosing healthy seed ($N = 225$)	Kaptama ($N = 75$)	Saboti ($N = 66$)	Lelan ($N = 84$)	Total
Examine the seed tubers ($N = 225$)	71	57	80	208 (92.4%)
Visit and examine the health of the crop in the field before harvesting ($N = 225$)	62	44	64	170 (75.6%)
Other choice[a] ($N = 225$)	30	33	13	76 (33.8%)
Rely on the seed growers/supplier's information ($N = 225$)	10	24	10	44 (19.6%)
Use only certified seed or rely on information from potato experts ($N = 225$)	4	3	2	9 (4.0%)
Do not search or give much attention to seed health ($N = 225$)	2	3	0	5 (2.2%)

Each criterion is considered individually by all household respondents

[a]Options given—use seed from different soils/fields, cut seed to check bacterial wilt, examine yields at harvest, sort best own seed, rotate fields

Table 4 Farmers' options when healthy seed of preferred variety is not available

Criteria of choosing healthy seed ($N = 225$)	Katama ($N = 75$)	Saboti ($N = 66$)	Lelan ($N = 84$)	Total ($N = 225$)
Plant same seed they already have ($N = 225$)	41	38	58	137 (60.9%)
Suspend potato for another crop ($N = 225$)	51	38	41	130 (57.8%)
Purchase healthy seed of another variety ($N = 225$)[a]	43	26	21	90 (40.0%)
Use seed of unknown health of preferred variety ($N = 225$)	6	7	7	20 (8.9%)
Other option ($N = 225$)[b]	0	2	12	14 (6.2%)

[a]Lelan farmers could have provided information based on previous experiences on growing of other variety options, Shangi being the sole current variety grown

[b]Leave land fallow, not renewed seed for over 10 years, rotate plots, prepare or plant own seed early in a separate field

Table 5 Percentage of household respondents and ranking of different criteria for decision to renew seed of a preferred potato variety in three survey sites in north-west Kenya

Criteria for decision to renew seed	Kaptama ($N = 75$)	Saboti ($N = 66$)	Lelan ($N = 84$)	Overall ranking[a]
When there is a decline in yields ($N = 225$)	91%	86%	89%	1
When seed is infected with diseases ($N = 225$)	76%	71%	89%	2
How long the seed of the variety is grown/recycled ($N = 225$)	11%	24%	12%	3
When new 'clean' seed is available ($N = 225$)	23%	15%	6%	4
When certified seed is available ($N = 225$)	0%	4.5%	6%	5

[a]Ranking done based on the overall percentage of respondents

Table 6 Frequency of renewing seed potato amongst respondents

Frequency of renewing seed for planting	Number of respondents ($N = 225$)
Once in more than 5 years	29 (12.9%)
Every 5 years	20 (8.9%)
Every 4 years	25 (11.1%)
Every 3 years	57 (25.3%)
Every 2 years	54 (24.0%)
Every year	33 (14.7%)
Not sure	6 (2.7%)
No response	1 (0.4%)

only renewed seed once every two to ten or more seasons since there were mainly two crops per calendar year. Those few respondents who had planted certified seed indicated that they renewed/replaced their seed every year to once in more than every 5 years. The frequency of renewal of home saved seed was mainly once per two to three years but some respondents renewed after 4, 5 or more than 5 years (Table 6). The 'renewing' of seed was perceived in different ways as it involved mainly selection of 'healthy' seed from farmer's own crop particularly from a different field or in a worse situation (of unknown status) replaced with seed from a neighbour's seed source. The partial hypothesis that 'variety choice is determined by availability and access to healthy seed' *partly* holds true, since the farmers' decision on varieties is limited by access and availability of seed, where the majority is dependent on home saved seed, of which they attempt to improve the seed health by on-farm selection.

Survey respondents named 24 different varieties comprising the current and the previously grown varieties during the previous two rainy seasons (Table 7; Supplementary Material 4). The survey focused mainly on the current popular varieties Shangi (80%), Arka (12%) and Kabale (5%) where the latter two varieties were grown mainly in Saboti and Kaptama alongside Kenya Karibu, and Markies and Konjo in Lelan in small quantities. Although an elaborate formal seed potato system exists in Kenya and is strong in some areas, the results indicate that it was non-functional in the study areas making the informal seed system the most popular (Table 7). Most farmers obtained seed and consequently the varieties they grew from this system. All varieties that have been introduced through the formal seed system were found to make their way to the informal system. The popular varieties persist within the informal seed system while others 'disappear'. The respondents who had accessed seed from the formal seed system could be categorised as progressive farmers or by chance those who had interacted with seed potato merchants or other potato stakeholders.

Table 7 Frequency of potato varieties known to household survey respondents as from the informal and formal seed systems

Aggregated ($N = 225$)	Informal seed system	Formal seed system	Origin
Shangi	213	21	Informal
Arka	129	5	Formal
Kabale	127	–	Informal
Tigoni	81	4	Formal
Kenya Karibu	55	6	Formal
Black Karen	42	–	Informal
Nyayo	28	–	Informal
Annet	17	–	Formal
Desiree	13	–	Formal

Unica, Jelly, Destiny, Markies, Konjo and Manitou, and Asante, Sherekea, Limuru, Cheptuya, Local White and Dutch Robijn were new and old or previously grown varieties given by a low number (1–6) of respondents

During focus group discussions, participants deliberated on a total of 23 potato traits, which they ranked (Supplementary Materials 5, 6 and 7). Both male and female participants indicated the different traits they preferred and associated them with certain varieties they were growing, or they previously grew. In the trait preference ranking of the top ten, 'yield' was the most important trait, followed by 'disease resistance', then 'market demand' and at the bottom, 'processing quality' (Fig. 2). Overall, the women gave more preference for high market demand, early maturity and tuber size, whereas the men indicated more preference for taste, processing quality and storability. Tuber shape and shallow eyes were not given strong consideration by either men or women.

Participants gave their reasons for the preference of each preferred trait (Supplementary Material 4). They indicated that high tuber yields translated into more income and increased food supply, while disease resistance helped in reduction of crop losses, use of pesticides, cost of production and risk to human health and increased environmental safety. In many cases, the disease resistance referred to here was late blight (*Phytophthora infestans*), which farmers also associated with frost or cold and hence referred to as *barafu* (cold/frost). Market demand was the third highest ranked 'trait', while market related traits (long storability, tuber size, taste, processing quality, shallow eyes and tuber shape) ranked lower. Early maturity was the 4th most preferred trait across study areas because it contributed to early income, higher prices, early food supply/reduced hunger and with early planting, and allowed other crops to be planted in the year. Long or good storability was ranked 5th across counties. Tuber size was ranked the 6th most preferred trait, with

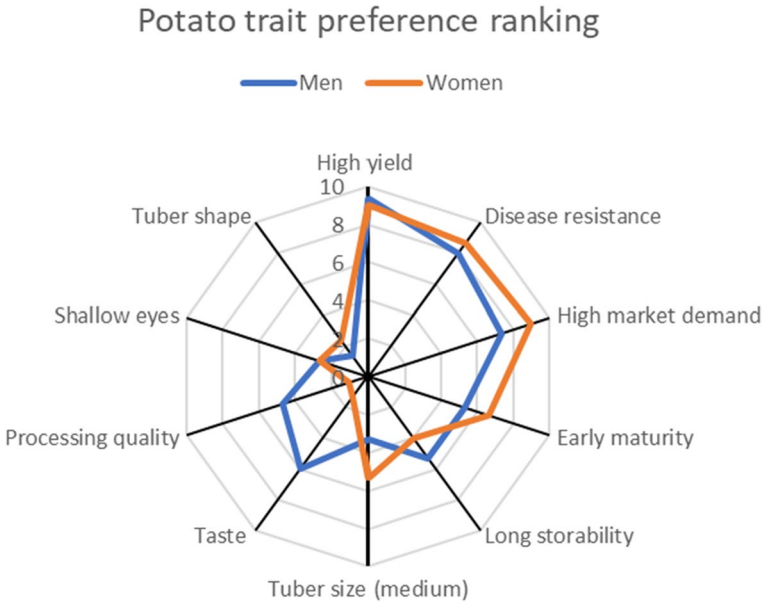

Fig. 2 Radar chart of preference ranking of potato traits by men and women focus group participants across three study areas in north-western Kenya

Table 8 Respondents' ranking of some agronomic resilience and productivity options as main factors that guide in choice of varieties to grow

Main factors that guide choice of variety to grow	Mean rank	Priority rank
Disease resistance	2.17	1
High yields	2.28	2
Not easily degenerated or ease of recycling	2.59	3
Early maturity	2.97	4

medium size associated with yield and ease of selling (attractive to customers). Taste was ranked the 7th overall preferred trait with the reason that it meets the needs of the market. Shallow eyes were ranked the 8th preferred trait across the three survey sites, a quality that ensures less wastage during peeling. Tuber shape was ranked 9th since it contributed to easy selling. Tuber processing quality was ranked 10th because it attracted the market particularly for chips and that it brought profit.

During the household survey, respondents were also asked to rank twelve factors or traits which guided them in choosing a variety to grow from most important to least important based on agronomic resilience and productivity. By 'agronomic resilience' we meant the ability of a variety to perform well when compared to other varieties under the prevailing conditions for example in resistance to disease pressure, drought tolerance, early maturity and ease of recycling, while productivity refers to the yielding capacity of a variety. The top four most important factors and their mean ranking from 1 to 4 across the study sites are shown in Table 8. The results indicated that 'disease resistance' was the most important factor, followed by 'high yields', 'having ease of recycling (for seed) over many years' and finally 'early maturity', which were comparable to the reasons from the focus groups.

When asked about factors contributing to low potato yields of the varieties they grew, respondents selected and ranked as first choice options; insect pests and diseases (44.9%) followed by poor seed quality and source, inadequate technical knowledge of farmers, soil fertility problems, weeding management and, finally, varieties grown (Table 9). Although few varieties were grown by farmers, the high ranking of importance given to agronomic resilience traits (Fig. 2) and the factors contributing to low yields (Table 9) provide evidence to support the partial hypothesis that '*variety choice was determined by both agronomic resilience and productivity*'.

Table 9 Household respondent ranking of factors they considered to contribute to low potato yields of the varieties they grow

Limiting factor for low yield	First choice factor	Second choice factor	Rank
Insect pests and diseases ($N = 225$)	101 (44.9%)	63 (28.0%)	1
Seed quality and source ($N = 225$)	45 (20.0%)	55 (24.4%)	2
Inadequate technical knowledge ($N = 225$)	34 (15.1%)	39 (17.3%)	3
Soil fertility problems ($N = 225$)	34 (15.1%)	38 (16.9%)	4
Weeding management ($N = 225$)	6 (2.7%)	20 (8.9%)	5
Variety(ies) grown ($N = 225$)	5 (2.2%)	10 (4.4%)	6

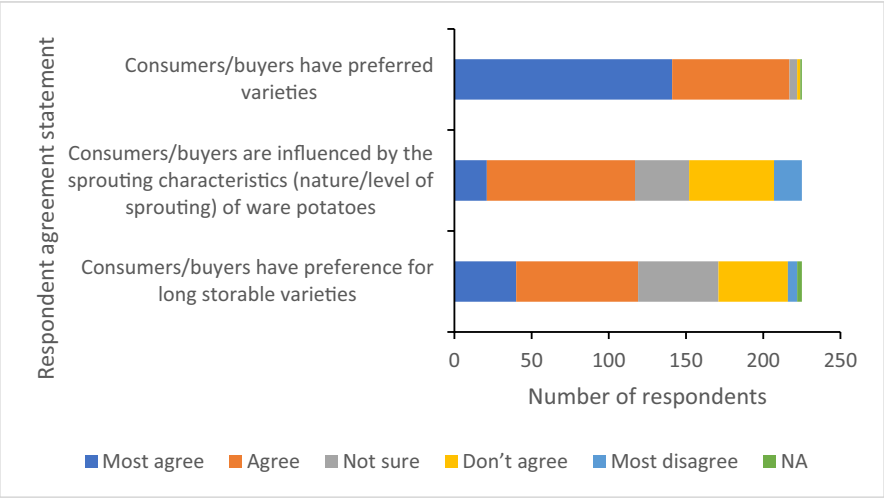

Fig. 3 Respondents' perceptions of consumer preferences

In the household survey, farmers were asked to give their level of agreement with a number of statements about consumer variety preferences. Figure 3 shows that respondents most agreed that consumers have clear preferences for varieties. Most (78%) respondents indicated that the type of varieties that were most marketable were those suitable for chips, while 17% were of the view that the variety preference was similar for both chips and cooking/table, 2% for cooking and 3% were not sure (Supplementary Material 8).

Respondents were asked about their own preferred varieties and the varieties preferred in the market. The variety Shangi was the most preferred both by the farmers and market in almost equal measure followed by Kabale and Arka (Table 10; Supplementary Material 9). During FGDs, the popularity of Shangi was explored and participants explained that it was widely grown because it had high market demand, and was relatively high yielding, early maturing, fast cooking, moderately disease resistant, easy to harvest (shallow depth) and had the right level of flouriness/mealiness, desirable medium to large tuber size, oval tuber shape, fast sprouting for seed, good taste, less requirement for frying oil, early ground cover and uniform tubers. Focus group participants in Saboti indicated that Arka had some tolerance to diseases, desirable skin colour (light red), tuber size (medium), drought tolerance, good keeping quality/storability ('does not spoil easily') and shallow eyes. They also indicated that Arka was resilient or persistent in the field and would regrow easily as volunteer plants, an attribute that contributed to its persistence over many years, particularly in Saboti and Kaptama.

Participants in Kaptama and Saboti affirmed that although they had not accessed new seed of Arka for a long time, the variety was still being grown by farmers despite the low yields realised. This variety also fetched a higher price in supermarkets (personal observation by the first author). Participants in Saboti indicated that the variety Kabale from Uganda was new and high yielding. They added that

it tuberised near the soil surface making it easy to harvest and had shown increased market demand, which had made farmers eager for it.

According to focus groups, some of the new varieties such as Jelly, Manitou, Markies and Destiny introduced in Lelan were not embraced by farmers because of late blight damage and the unfavourable environment and possibly their unknown marketability. Other varieties, such as Konjo, Unica and Wanjiku, were new and known by a small number of farmers, while their acceptance by the market was still unknown to the farmers.

Hypothesis 2: Understanding of dormancy and physiological seed quality by farmers is masked by variety choice

In order to understand farmers' perceptions about seed quality and variety choice, they were asked questions related to their knowledge and practices on tuber dormancy and physiological age. Across the study sites, respondents indicated that they were aware that potato varieties showed short (96.0%), medium (75.1%) or long (81.8%) dormancy types, treating each dormancy type independently. Respondents classed varieties in the short, medium and long dormancy types, with the popular variety (Shangi) classified as short dormancy (Table 11). Results showed that farmers did not clearly differentiate between medium and long dormancy as shown by their classification of Arka and Kabale. Respondents ranked short dormancy as most preferred (79.1%), medium dormancy as preferred (60.4%) and long dormancy as least preferred (40.9%). In choosing a new variety to plant independent of what the market wants, 76% of the respondents across the study areas indicated that they considered dormancy, although there were differences across the three areas with 85%, 81% and 64% respondents in Saboti, Kaptama and Lelan, respectively, indicating that they considered dormancy in choosing varieties.

There was some divergence between the farmers' views and dormancy experimental results from another study where Arka showed very short dormancy as Shangi (Kwambai et al. 2023). Farmers classing Shangi as short dormancy type, in agreement with the experimental findings, showed that farmers had a good understanding about its dormancy. Their understanding of other dormancy types was difficult to fully determine since a negligible number of other varieties were grown by few farmers. The value of the dataset in evaluating the hypothesis is limited as most farmers grew Shangi, while a small number grew Kabale and Arka mainly in Saboti and Kaptama, and all other varieties were grown by a very small number of farmers (Kwambai et al. 2022). It was difficult to assess farmers' true understanding of seed quality relative to variety due to the domination of Shangi in the study areas. Few other varieties were of short dormancy, and 54.7% respondents indicated Shangi as predominantly a short dormancy variety. There were more varieties with long dormancy according to most respondents, with Arka and Kabale considered to have the longest dormancy followed by Black Karen, Annet and Kenya Karibu in that order (Table 11). Tigoni was indicated by most respondents as of medium dormancy followed by Kenya Karibu.

On sprouting of seed tubers, focus groups participants in Kaptama and Saboti explained how they managed (prepared or treated) their seed potato after harvest for immediate planting. The seed tubers were left to harden in the sun or in storage for a few days, then placed on leaves of the common shrub boldo (*Peumus boldus*) or other suitable vegetation, and then covered with the same leaves and a layer of soil on top so as to make a mound in the field or around the homestead, a method popularly known as '*bedding*' (Fig. 4A). However, those in Lelan indicated that they stored their seed tubers in gunny bags in the store or house, which is usually warm or left them in the field exposed to the sun (Fig. 4B). During the household survey, we asked farmers the open question, 'with a variety that takes long to sprout, how do you ensure it sprouts fast for immediate planting, particularly for the short rainy season planting?' The responses in Saboti and Kaptama confirmed the use of '*bedding*' in hastening sprouting by over 93% and 81% of the respondents, respectively. In Lelan, most respondents indicated that they put the seed in gunny bags and stored it in a warm part of the house (kitchen) or in store and covered it with some dry grass, crop residue or polythene sheet. Others stored seed in pits or covered it with farmyard manure. They also added that on most occasions the seed was first exposed to the sun to warm before storage.

Respondents were also asked how they ensured that varieties that sprouted within a short period delayed their dormancy break, particularly from the short rainy season harvest (November/December) to the long rainy season planting (March/April). Although responses were diverse most respondents indicated that they kept the seed in store and spread it without covering. Others also indicated that they kept it in the house spread out without covering.

In order to understand their awareness and perceptions on the effects of dormancy and its characteristics on seed potato for planting, respondents were asked whether they sometimes experienced uneven or delayed emergence from low sprouting, excessive sprouting or rotting during both the long and short rainy seasons. Most

Fig. 4 Farmers' innovation(s): **A** dormancy breaking **s**eed treatment referred to as 'bedding' for early sprouting of seed tubers in Saboti and Kaptama and **B** Storage of seed potato tubers in gunny bags in the field in Lelan

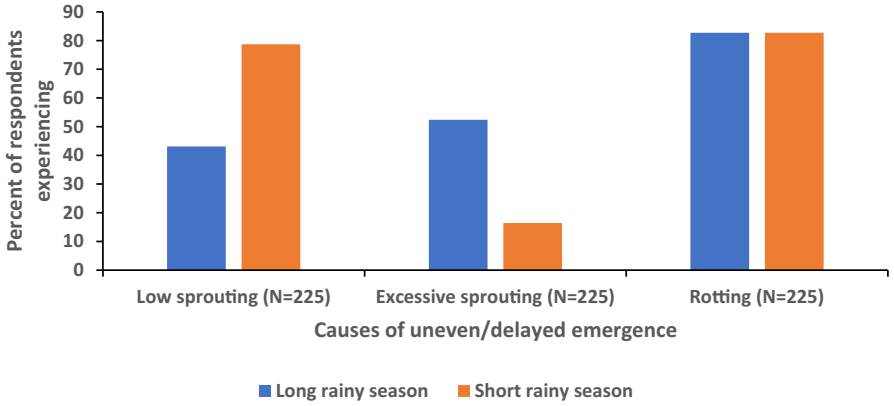

Fig. 5 Percent of household survey respondents experiencing uneven or delayed emergence sometimes after planting seed potato during the long and short rainy seasons across study sites

(82.7%) respondents across the study sites indicated that they sometimes experienced uneven or delayed emergence as a result of rotting during both the long and short rainy seasons (Fig. 5).

Others indicated that they had experienced uneven or delayed emergence due to low sprouting and excessive sprouting**.** Generally, rotting was the main cause of uneven or delayed emergence followed by low sprouting and then excessive sprouting, with seasonal differences in low sprouting and excessive sprouting. Rotting was a problem during both seasons with Lelan being the most affected, and similarly for low sprouting (Fig. 6). Excessive sprouting was more in the long rainy season than in the short rainy season. Most household survey respondents indicated that uneven or delayed emergence led to yield losses in the range of < 10% or sometimes 11–25%, with rotting being the most common in both seasons and excessive sprouting high in the long rainy season (Fig. 5; Supplementary Material 10).

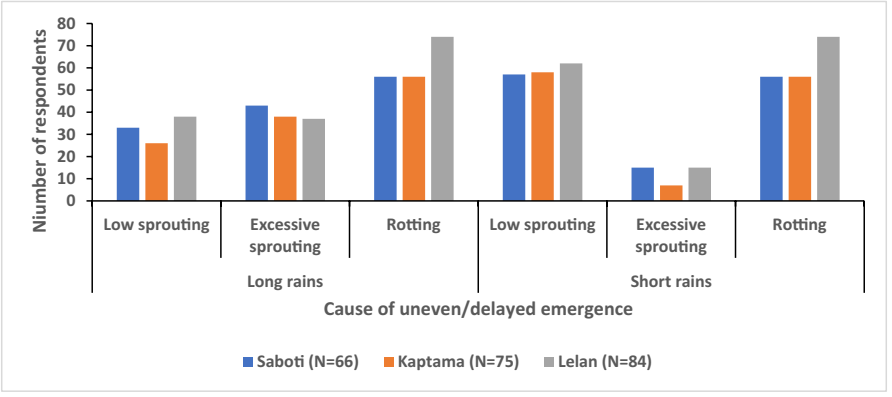

Fig. 6 Household survey respondents' perception on causes of uneven/delayed emergence of potato varieties after planting in the long and short rainy seasons in three study sites

Hypothesis 3: Variety choice is influenced by ware quality and storability

Most household survey respondents did not store their ware potatoes (Fig. 7). However, some stored for food in conventional stores (usually ventilated and raised above the ground), left them in the field for harvesting as required or stored them in the house in heaps or sometimes in bags or even sometimes in a pit outside. Farmers in all study sites sold their produce directly after harvest without storing except for household food. From the respondents and through observations during the survey, it appeared that most farmers had little interest in the storage of ware potatoes across the three potato growing areas.

Amongst the top six varieties, Arka was indicated as most suited for long storage followed by Kabale, Black Karen, Tigoni, Kenya Karibu and Annet, while others were considered to be of low storability including Shangi because of the short dormancy. Respondents were asked to give their views on three statements regarding the advantages of ware potato storage (Fig. 8). Over 73% of the respondents indicated that the statement, 'storage of ware potatoes improved market prices' was true followed by that 'it allows them to make more income', but also 'brought about losses' sometimes.

Discussion

Farmer's Decisions on Variety Choice Are Influenced by Availability and Access to Healthy Seed

Three main factors were examined to understand their influence on farmer's varietal preferences: (1) access and availability of healthy seed; (2) agronomic traits and productivity; and (3) market demand. While seed certification is the best guarantee of quality healthy seed potatoes, Mulema et al. (2021) and Atieno et al. (2023)

Fig. 7 Ware potato storage methods and number of household survey respondents practising

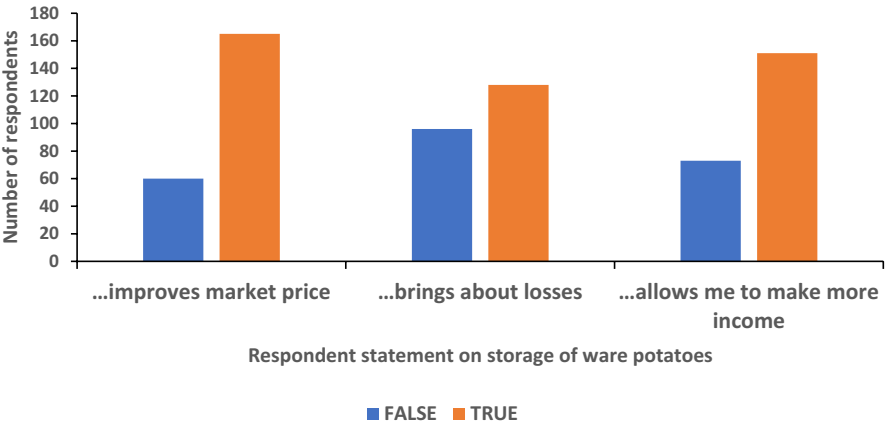

Fig. 8 Respondent perception statement on storage of ware potatoes

highlighted the low availability and usage of certified seed potato in Kenya, which was confirmed in our study. While there are more seed companies currently producing seed potato of several varieties (NPCK 2017; NPCK 2021) compared to 5 years ago, their impact on quality seed access in north-western Kenya is still small. The vast majority of farmers do not have access to new varieties that are being introduced. The few respondents who had used certified seed valued the attributes of high yields and avoidance of diseases, suggesting that increasing farmers' exposure and access to quality seed could increase yields (cf. Atieno et al. 2023).

Despite the growth in the commercialisation of certified seed (Komen et al. 2017; Janssens et al. 2013; NPCK 2021), seed merchants are not reaching the majority of smallholders who continue with the variety(ies) they were used to and the use of the informal seed system (own, neighbour saved seed or local market). However, the growth in the number of seed merchants (NPCK 2021) suggests that the Kenyan situation could change dramatically with a better strategy in seed distribution of market demanded varieties at affordable pricing. Within the informal seed system, most farmers across the study sites indicated that they actively seek for 'healthy seed' of their preferred variety(ies), which showed that they understood the need for planting healthy seed, but may require proper tools and knowledge to ascertain seed health. Those at lower altitudes emphasised more on the search for 'healthy seed', possibly because they experienced more disease problems such as bacterial wilt than farmers at higher altitudes. The different criteria the farmers used to ensure the seed is healthy (Table 4) highlighted the needs for training. Most respondents only examined tubers while some visited and examined the crop before harvesting to ensure they got 'healthy seed'. Training could help farmers acquire knowledge and skills for better techniques such as positive and negative selection (Gildemacher et al. 2011).

The variety Shangi was the dominant and most preferred variety across all study sites. Where farmers could not find healthy seed of their preferred variety, those in the lower altitude sites were more likely to opt to grow other crops, whereas those in Lelan would grow potato even if they had concerns about seed health (Table 4). The low quality of seed most farmers use is likely one of the major contributors

to the low yields realised (Kwambai et al. 2022). Most farmers save their own seed and are slow to renew possibly because of the cost involved in acquiring seed outside the household. They lack knowledge and practical experiences with certified seed potato, worsened by the inaccessibility. Most farmers believed that changing seed from one field to another improved productivity, which means that seed renewal does not always imply a farmer getting new seed from a source outside the household but rather changing fields. Our study confirms that farmer's saved seed is often small and very much degenerated as a result of the uncontrolled nature of the informal system.

Our findings show that the formal seed system feeds into the informal seed system (Table 6) with varieties that originated in the formal system being found in the informal system. The predominant use of the informal seed system was influenced greatly by the inaccessibility of formal seed and the weak socio-economic capabilities amongst farmers. Although Arka was indicated to have attributes that contributed to its persistence over many years, particularly in Saboti and Kaptama, in another study currently under review, we found that the same variety had the lowest yield and was susceptible to late blight.

In the study areas, a few farmers had accessed newly released varieties from the formal system such as Destiny, Markies, Jelly and Manitou, which are of European origin (NPCK 2017). With time, these varieties are expected to diffuse into the informal seed system. A stronger mechanism could be put in place for the two systems to coexist to ensure regular replenishment of seed as farmers get trained on use and benefits of quality seed. Almekinders et al. (2021) working on maize suggested an inclusive demand-oriented breeding and seed system with the need to develop and support different delivery pathways to fit farmers' diverse use of seeds and varieties, a consideration that would increase access to seed potato despite the differences in seed potato system from that of grain crops.

Productivity, Agronomic Resilience and the Demands of the Market

In the three study areas, historically there was a wider range of varieties grown and sold in the markets, with a total of 29 varieties mentioned. However, this situation has changed following the entry of Shangi, and possibly changes in market preferences. The importance of understanding farmer preferences for variety traits has been emphasised by many authors (e.g. Kolech et al. 2017; Forbes et al. 2020). In this study, farmers identified 'yield' as the most important trait, followed by 'disease resistance', 'market demand' and at the bottom 'processing quality', as important 'traits' for selection. However, the study found that previously desired varieties ended up being replaced by new ones (such as Shangi and Kabale), indicating evolution in both farmer and market preferences. For example, disease resistance to late blight (*Phytophthora infestans*) is important to farmers; however, several late-blight tolerant, improved varieties are available in Kenya, with limited adoption by farmers, probably due to their low marketability. Also, the issue of seed and/or variety degeneration could play a role in farmers losing interest in a variety so long as there was an alternative. Market demand of a variety seemed to be a key driving factor for adoption. A blend of agronomic

Table 10 Farmers' and market preferred varieties as perceived by household survey respondents and ranking

Variety	Farmer preferred	Rank	Market preferred	Rank
Shangi	222 (98.7%)	1	224 (99.6%)	1
Kabale	124 (55.1%)	2	129 (57.3%)	2
Arka	112 (49.8%)	3	110 (48.9%)	3
Kenya Karibu	26 (11.6%)	4	24 (10.7%)	4
Tigoni	18 (8.0%)	5	17 (7.6%)	5
Black Karen	12 (5.3%)	6	5 (2.2%)	6

Nyayo, Annet, Asante, Desiree, Sherekea, Markies and Unica were reported to have low preference by both farmers and the market according to a small number (1–7) of respondents

traits with market demand appears critical for cultivars to be readily adopted (Muthoni et al. 2013). Besides the disease incidences and lower adaptability of some of the new varieties, their unknown marketability could have contributed to their rejection in Lelan and other areas. The same varieties may require a higher

Table 11 Perceived short, medium and long dormancy of potato varieties currently and previously grown by respondents compared with experimental results

Variety	Short dormancy	Medium dormancy	Long dormancy	Experimental results
Annet			15	Long[a]
Arka		48	68	Very short[b]
Asante		1		Medium[b]
Black Karen		5	19	
Chebirirkut		1		
Cheptuya		6	6	
Desiree		2	2	Long[b]
Jelly		3	3	Medium[a]
Kabale		54	55	
Kenya Karibu	2	10	9	Medium[b]
Konjo		1	1	Short[b]
Markies		1	1	Medium[b]
Nyayo	1	3	6	Short[c,d]
Shangi	214	1		Very short[b]
Sherekea		1	1	Late[b]
Tigoni		49	6	Short[b]
Unica			1	Medium[b]
Wanjiku		1	1	Long[a]
Total	217	187	194	

[a]NPCK (2017)

[b]The dormancy types shown against varieties were obtained from a separate study we conducted (Kwambai et al. 2023)

[c]Short dormancy (Kaguongo et al. 2008)

[d]Short dormancy (Crismann 1989)

level of management, which farmers were not used to, but for which farmers also lacked knowledge (Komen et al. 2017).

Despite the release of over 60 varieties in Kenya (Lung'aho and Schulte-Geldermann 2016), the variety Shangi was overwhelmingly the most preferred variety by the market, and similarly by farmers (Table 10). Farmers showed knowledge and appreciation of the different qualities of different varieties. In Lelan, they discussed the previously popular variety Cheptuya which was displaced by Nyayo, further displaced by Black Karen, then Tigoni and currently Shangi. In Saboti and Kaptama, farmers associated Arka with disease resistance, drought resistance, good keeping quality/storability and field persistence/low degeneration, but its production had drastically declined, possibly due to lack of seed renewal. Storability was moderately valued (although storage was rarely practised) as it enabled farmers to store their potatoes for household consumption, seed and ware potatoes for sale possibly to target better prices later after harvest. However, Shangi has low storability, so the strong market demand and its other traits appear to override the importance of storability.

Farmers also showed an understanding of the (value of) different agronomic traits associated with different varieties. Farmers ranked tuber yield, disease resistance and early maturity as important agronomic traits. The variety Kabale, which is registered and cultivated in Uganda (Kakuhenzire et al. 2004), was said to tuberise near the surface, making harvesting easier. Early maturity is important for food security and early income for households (Sinelle 2018), also allowing more crops in a year in areas with high land pressure (Kaguongo et al. 2008), especially at high altitude or where farmers access supplemental irrigation. Shangi has a moderate susceptibility to late blight, but it appears to have a (currently) winning combination of farmer preferred traits such as short dormancy with those demanded in the market—high yield, early maturity, taste, shape and processing quality.

Despite agronomic attributes, market demand featured as a primary determinant of variety choice amongst farmers. Most potatoes grown in Kenya are processed for chips, particularly in urban centres for fast food restaurants, eateries and open street vendors (Fintrac 2015), and farmers recognise that varieties suitable for chips were most preferred, especially Shangi (NPCK 2017) and previously Tigoni and Nyayo (Kaguongo et al. 2008).

How Farmers Understand Dormancy and Physiological Age in Seed Potato

Factors determining crop yield are influenced by seed quality (Struik 2007), which may include seed health and the inherent dormancy and physiological age. Although farmers in this study did not fully understand the science behind dormancy and physiological age, they had some knowledge to handle issues of dormancy, and varieties with short dormancy were the most preferred types. Most farmers grew Shangi, which has short dormancy while others grew Kabale and Arka specifically in Kaptama and Saboti. In a related storage experiment, Kwambai et al. (2023) reported Arka as a very short dormancy variety, which was contradictory to the household survey respondents who indicated that it had medium or long dormancy (Table 11).

Farmers value varieties that break dormancy early to meet the short time interval between harvesting at the end of the long rainy season and planting at the beginning of the short rainy season. Such varieties ensure a potato crop planted will emerge with vigour and establish successfully within the short growing season. Kaguongo et al. (2008) found that farmers considered length of seed dormancy in Kenya and Uganda for purposes of timely planting in the subsequent season. Also, Lung'aho and Schulte-Geldermann (2016) found that farmers abandoned many varieties with long dormancies in favour of varieties with short dormancy periods. Dormancy challenges have led farmers to come up with their own innovations to hasten dormancy breaking as in the case of 'bedding' in Saboti and Kaptama (Fig. 4A); however, the majority settle for short dormancy varieties irrespective of the seasons but rely on left over tubers at harvest as seed material after selling the main produce. The dormancy breaking practices showed that farmers were aware that potato needed some stress conditions or treatment in order to sprout faster. Also, they used *P. boldus*, which they believed released some beneficial substance(s) (e.g. phytohormones) for sprouting, and this would warrant further investigation.

Ideally, farmers should have access to adaptable and desirable varieties during the short period between the end of the long and beginning of the short rainy seasons (July/August–September/October) and long period between the end of the short rainy season and the beginning of the long rainy season (December–March/April), supported by appropriate dormancy or dormancy breaking practices that are convenient and user-friendly to meet seasonal requirements.

Conclusion and Recommendations

The factors influencing variety choice were found to revolve around seed availability, access and quality, agronomic resilience and productivity and market demand. The potential of certified seed potato to increase yields and production is curtailed by its unavailability in the study areas. There is a need for access mechanisms to allow and promote continuous or regular farmers' access to quality seed of different high-yielding varieties that can be further spread through farmer-to-farmer seed diffusion. Generally, the seed and varieties grown widely by farmers are sourced locally, limiting renovation of seed and diversification of the varieties grown and thus creating an unproductive circle where seed is recycled particularly within the growing areas and region.

Establishment of active linkages between farmers and the formal seed actors could enhance dissemination of new varieties through seed supply in the study areas considering the long distance between these production areas and the seed growing areas. Farmer-sensitive initiatives in the seed distribution system are recommended in terms of making seed accessible and affordable with enhanced farmer-seed merchant interactions for improved production and sustainability.

The lack of diversification of varieties increases vulnerability in the potato subsector and calls for interventions to broaden varieties available to farmers that meet the different environmental and socio-economic needs without compromising the market demand. The trait preferences (e.g. yield, disease resistance, 'market

demand' attributes, early maturity) should provide useful information for breeding varieties for Kenya and SSA. In addition, inclusion of varieties with desirable attributes such as different dormancy types could contribute to early and uniform crop establishment, and enhanced storability. Planting different varieties in different seasons could solve dormancy and adaptation problems. Farmer awareness and training is recommended to eliminate the lack of knowledge on the various technical aspects of variety, seed, crop management and even marketing. In general, understanding farmer practices is imperative to guide introduction and cultivation of new varieties.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11540-023-09626-8.

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Ethics Approval The farmers involved in the focus group discussions and the household respondents were informed that taking part in the study (with KALRO and partners) was voluntary and the information collected would be kept safe in confidence and would be used only for the purpose of the research conducted. Subsequently, all farmers involved gave their informed consent.

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Data Availability All data are available in the Supplementary material.

Declarations

Conflict of Interest Denis Griffin is Processing Editor of Potato Research; Paul C. Struik is Editor-in-Chief of Potato Research.

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