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Understanding Potato Production Practices in North-Western Kenya through Surveys: an Important Key to Improving Production

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Abstract

Potato is the second most important food crop after maize in Kenya. However, most farmers produce potatoes under sub-optimal management, resulting in low yields, despite the introduction of improved varieties. Potato production practices were documented and compared to contribute towards improved potato management and productivity in Kenya. The study was guided by the hypothesis that potato farming and management practices influence potato performance and can depend on the production environment. Focus group discussions and household surveys were conducted in three major potato growing areas in Kaptama, Saboti and Lelan in Bungoma, Trans Nzoia and Elgeyo Marakwet counties in Kenya. Farming was the main occupation of 58.2% of the respondents. Respondents across the study sites indicated that they grew potatoes with their main focus as a cash (83.6%) and food (16.4%) crop. Most respondents had planted potatoes during both the last long (96.4%) and short (92.4%) rainy seasons**.** The four most important constraints limiting optimal potato production according to respondents were lack of quality seed, diseases (specifically late blight and bacterial wilt), poor marketing and lack of adequate technical knowledge on potato management. Low yields realized by farmers were mainly influenced by poor farmer practices in the use of seed, fertilizers, pesticides and crop rotation. This was compounded by farmers' perceptions on input quantities applied, frequencies and farmers' access to agricultural extension information on potatoes, which heavily relied on family members and neighbouring farmers. Provision of quality seeds and training of farmers with the support of demonstrations on fertilizer and pesticide and appropriate crop rotation practices are recommended for improved potato production and yields. Use of irrigation where possible should be enhanced through government and development partners' support to ensure sustainable potato production and supply. Also, the use of viable extension information channel(s) could enhance potato production for household food security, livelihoods and national goals.

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Introduction

Potato (*Solanum tuberosum* L.) is the most important non-cereal crop in the world (Struik and Wiersema 1999), and now the world's third most important food crop in terms of human consumption, after wheat and rice (FAO 2013). In the tropics, potato cultivation faces seed, soil fertility and crop management challenges (Gildemacher et al. 2009; Muthoni et al. 2013). In Kenya, potato is the second most important food crop after maize and is highly commercialized across its value chain. About 2–3 million tonnes of potatoes worth Ksh. 40 to 50 billion (US$ 345–431 million) are produced each year and engaging millions of Kenyans (MoAL&F 2016). Traditionally in Kenya potatoes are mainly grown in the highlands (Crissman et al. 1993), where it is generally cool at altitudes from 1500 to 3000 m (Jaetzold and Schmidt 1983; Kaguongo et al. 2010; Janssens et al. 2013), and rainfall is relatively abundant and increases with altitude (Crissman et al. 1993). The potato crop is grown twice a year during the long and short rainy seasons (Gildemacher et al. 2009; Janssens et al. 2013), with limited irrigated areas (Lung'aho and Schulte-Geldermann 2016). While the area under production continues to increase, potato yields continue to decline (Lung'aho and Schulte-Geldermann 2016). The increase in the area under potatoes is attributed to an increase in the number of growers and land put under the crop. The common use of farmer-saved seed and inadequate crop management contribute to the low yields realized by farmers.

Most farmers produce potatoes under sub-optimal management, resulting in low yields (Nyankanga et al. 2004; Gildemacher et al. 2009). Komen et al. (2017), working with researcher-managed trials, found that intensive management of potatoes gave sustainably high yields, contributed by factors other than the variety. Focus group discussions (FGDs) used alone or alongside other methods such as household surveys (Freitas et al. 1998) could provide opportunities to understand farmers' practices and their perceptions. Also, focus group discussions help explore issues that are not well understood or where there is little known prior research (Vaughn et al. 1996; Freitas et al. 1998; Ochieng et al. 2018).

In March 2018 and from July to September 2019, a series of focus group discussions and household surveys were conducted with potato farmers in three major potato-growing areas in north-western Kenya to understand potato production practices in those areas. The study was carried out to answer the hypothesis that "potato farming and management practices influence potato performance and can depend on production environment" (location, season, management, biotic and abiotic stresses). This paper therefore investigates potato production practices in three locations at different altitudes (2100 to 2300, 1803 to 2354 and 2641 to 3061 m above sea level) to gain a greater understanding of the crop management constraints and practices that limit potato productivity. The use of seed, fertilizer, biocides, crop rotation and treatment of volunteer plants and harvesting practices are described, and their association with yield is examined and suggestions for enhanced practices towards increased and sustained productivity are made. The paper presents useful information to understand the circumstances under which potatoes are grown in the study areas for present and future improvements. The paper concludes with several recommendations for extension service priorities.

Materials and Methods

The study sites are part of the 16 major potato-growing areas in Kenya. Generally, they have relatively poor road networks particularly in Saboti, Kaptama and Lelan in that order coupled with the hilly land terrain and are far from the main potato markets such as Mombasa, Nairobi, Nakuru, Kisumu, Eldoret and Uganda. As a result, they rely mainly on middlemen or brokers and a few small potato traders in the marketing of their produce. Also, they have less access to diversified farm inputs and limited extension service personnel.

Focus Group Discussions

Eighty-six active representative potato growers comprising men and women were selected through the assistance of agricultural extension personnel and key informant farmers for three focus groups, one in each site in March 2018. The study sites were

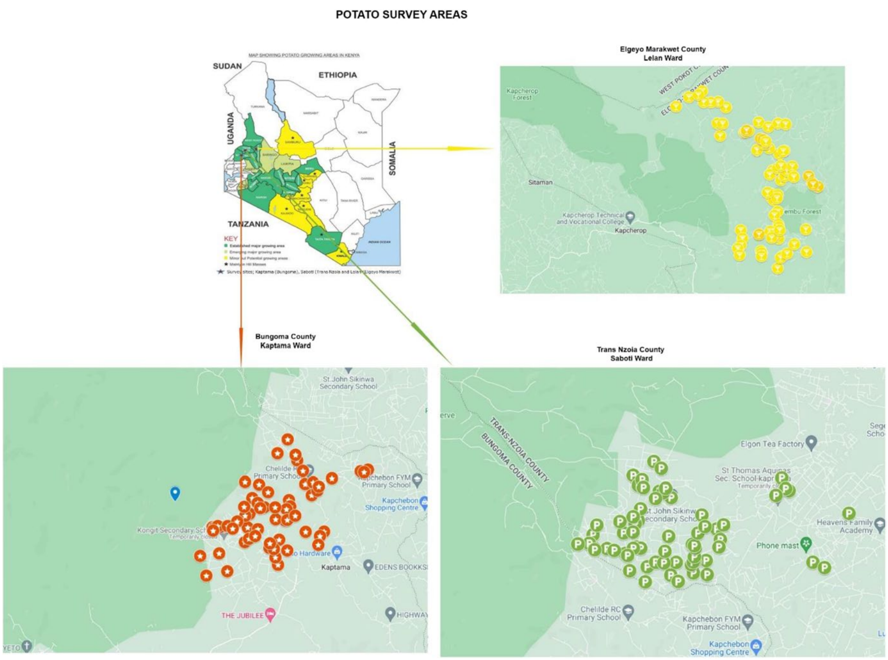

Fig. 1 Map of Kenya and Study survey sites in Kaptama (2100–2300 m), Saboti (1803–2354 m) and Lelan (2641–3061 m) above sea level and Global Positioning coordinate points of households interviewed. Source of map of Kenya: MoAL&F (2016). https://npck.org/Books/THE%20NATIONAL%20POTATO%20STRATEGY%20(2016%20-%202012)%20(2).pdf

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 (Fig. 1). Lelan is situated at the upper highland zone in Cherangani hills and Saboti and Kaptama are situated at the slopes of Mt. Elgon. Throughout this paper, the study areas are referred to by the name of the administrative ward where the studies were conducted. The study sites were selected purposively based on the high intensity of potato production and active potato growing in the three counties, and their proximity to each other relative to other growing areas in the region.

The focus groups provided preliminary baseline information on potato production practices, which partly informed an in-depth household survey that followed. During the focus groups, a checklist was used as a guide to capture data. The participants were grouped into male and female with each gender further split where possible into two groups comprising five to eleven persons for ease of conducting the focus groups. A list of 26 constraints in potato production based on the checklist and additions from participants was drawn by the participants on flip charts and these were discussed, and ranking was done by groups of gender as 1, 2, 3, … up to the n^{th} number of constraints with the most important ranked 1 and the least n^{th}. However, later this was harmonized by assessing the constraints and the number of times they were ranked by each gender-group and a subjective overall rank was awarded in the same order for each gender. For purposes of creating a radar chart for interpretation in Microsoft Excel (Ghebreagziabiher et al. 2021), the ranking was reversed such that 1 was given a score of n^{th}, 2 scores of $n^{th} - 1$, 3 scores of $n^{th} - 2$ and so on until n^{th} was given a score of 1. Additional information was obtained through phone calls to key informants and the relevant literature was reviewed. Data were analysed using descriptive statistics in the Microsoft Excel computer package.

Household Survey

A household survey was conducted between July to September 2019 using a semi-structured questionnaire (Supplementary Material 1 and 2) with the aid of Open Data Kit (ODK) using tablets or smart phones. The objective was to obtain in-depth information on potato production, production constraints and management practices to understand farmers' practices and perceptions. The surveys were carried out in the same areas as where the FGDs were conducted. The study sites were selected purposively as indicated in the FGD section. The survey was done with the assistance of five enumerators on each site. The enumerators were trained in each site after which they pre-tested the questionnaire on a few potato farmers in parts of the target areas prior to the actual survey.

The interviews were conducted on 225 respondents, comprising 61.8% male and 38.2% female respondents across the study areas, with slightly more female respondents in Lelan than in Kaptama and Saboti (Table 1). The respondents must have at least grown potatoes in the previous two long (March/April to August/September) and short (August/September to November/December) rainy seasons of 2018, which were the major references for the interviews. The respondents comprised 66, 75 and 84 potato farmers in Saboti, Kaptama and Lelan wards, which fell within different altitude

Table 1 Characteristics of household survey respondents

Participant characteristic	Ward			Total (*N*=225)	%
	Kaptama (*N*=75)	Saboti (*N*=66)	Lelan (*N*=84)		
Altitude (m asl)	2100 to 2300	1803 to 2354	2641 to 3061		
Total number of households*	6035	6545	3749		
Number of potato growers*	8800	8500	8000		
Average household size (persons)	6.7	6.7	6.2		
Gender of respondents					
Male	48	42	49	139	61.8
Female	27	24	35	86	38.2
Total	75	66	84	225	100
Mobile phone (N=225)	65	63	82	210	93.3
Smart phone (N=210)	11	14	25	50	22.2
Age range in years					
≤ 35	27	18	13	58	25.8
36 – 45	19	30	21	70	31.1
46 – 55	14	20	16	50	22.2
56 – 65	14	10	10	34	15.1
> 65	1	6	6	13	5.8
Total	75	66	84	225	100
Level of education					
Not gone to school	2	2	5	9	4.0
Primary	37	37	37	111	49.3
Ordinary secondary (O level)	33	22	31	86	38.2
Diploma	2	0	8	10	4.4
Advanced secondary (A level)	1	3	0	4	1.8
Degree	0	1	3	4	1.8
Other	0	1	0	1	0.4
Total	75	66	84	225	100
Land size under potato cultivation (hectares)					
≤ 0.405	15 (20.0%)	15 (22.7%)	4 (4.8%)	34	15.1
0.406 – 2.025	50 (66.7%)	36 (54.6%)	41 (48.8%)	127	56.4
> 2.025	10 (13.3%)	15 (22.7%)	39 (46.4%)	64	28.4
Total	75 (33.3%)	66 (29.3%)	84 (37.3%)	225	100

m asl meters above sea level. *Data from local Ward Agricultural Extension Officer(s)

ranges; 2100 to 2300, 1803 to 2354 and 2641 to 3061 m above sea level, respectively. The respondents were selected at random irrespective of farm size along defined routes across major potato growing areas in each ward but at least three or four farms apart as the enumerators judged and depending on the intensity of potato growing. The respondents at each household were 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 the second or third farm household was interviewed instead. Global positioning system (GPS) coordinates readings and altitude were recorded at the household level. The characteristics of the study areas and household survey respondents are shown in (Table 1).

Besides data collected on the questionnaire, additional notes were taken on issues raised by respondents and pictures were taken where necessary. Questionnaire data collected were cleaned and then submitted to an Information Technology expert at Kenya Agricultural and Livestock Research Organization (KALRO) Headquarters, where the data were assembled in Microsoft Excel. Upon resubmission, the data were then further cleaned and analysed using both the statistical software R (R Core Team 2019) and GenStat 19th Edition VNSI computer package (VSN International 2017). The analysis was achieved through the use of cross-tabulations, frequencies, ranking and correlation analysis. The farmer practices were categorized into good, fair, poor, very poor and do not practise for those who did not plant potatoes or did not apply the practice in question (Supplementary Material 3). The categories were arrived at by grouping farmers based on their practices relative to the recommended practice for potato management (Kabira et al. 2006). Productivity was measured by the yield of ware potatoes harvested per unit area, which in our case was a number of 50-kg or 100-kg bags per acre (0.4047 ha) and then converted to a hectare basis. A correlation analysis was done between yield and crop rotation, soil fertilizer, foliar fertilizer, fungicide, insecticide, treatment of volunteer plants, overall farmer agronomic practices and altitude (Supplementary Materials 4 and 5).

Characteristics of Respondents

The number of households was the highest in Saboti followed by Kaptama and lowest in Lelan, with the household size being large and the same in Saboti and Kaptama but low in Lelan (Table 1). Lelan has a larger area under potatoes and is at higher altitude compared to Saboti and Kaptama, which makes it a cooler environment, favourable for potato growing. The high intensity of potato growing in Lelan influenced the choice of a larger number of respondents (1.1% of potato growers) interviewed compared to Saboti (0.8%) and Kaptama (0.9%) despite the much lower number of households (Tables 1 and 2).

Most respondents were within the age range of 36−45 years followed by those of 35 years and below (Table 1). In Kaptama, most participants were young (who may not have been household heads but members) and only one respondent was above 65 years of age in the same ward. Most (95.5%) respondents had at least primary education, while 4% indicated that they had not gone to school, more (6.0%) in Lelan than in Saboti and Kaptama. Almost half of the respondents across the wards had attained primary (49.3%) school education and 38.2% secondary and 1.8% had degrees (Table 1). Among the respondents, 93.3% owned a mobile phone while 22.2% had a smart phone (Table 1). Most respondents cultivated potatoes on land ranging from 0.405 to ≥ 2.025 hectares across study sites but in Lelan more respondents had more than 2.025 hectares under potatoes compared to Kaptama

Table 2 Number of respondents who planted potatoes in the last long and short rainy seasons (those of 2018) and frequency of potato growing cycles in a calendar year in three study areas in North-west Kenya

Ward	Potato planting 2018		Potato growing cycles (yearly)			Access to irrigation
	Long rains	Short rains	Once	Two times	Three times	
Saboti (*N*=66)	62 (94%)	59 (89%)	5 (8%)	61 (92%)	0 (0%)	5 (7.6%)
Kaptama (*N*=75)	71 (95%)	65 (87%)	5 (7%)	70 (93%)	0 (0%)	20 (26.7%)
Lelan (*N*=84)	84 (100%)	84 (100%)	0 (0%)	72 (86%)	12 (14%)	31 (36.9%)
Total (*N*=225)	217 (96%)	208 (92%)	10 (4.4%)	203 (90.2%)	12 (5.3%)	56 (24.9%)

Long rains: March/April to August/September, Short rains: August/September to November/December

and Saboti where alternative crops were grown (Table 1). Few respondents cultivated potatoes on less than one acre of land in Lelan compared to Kaptama and Saboti (Supplementary Material 6).

More farmers received more than 75% of their farm income from potato in Lelan compared to Saboti and Kaptama because potato was the predominant crop grown in Lelan as a result of the high altitude and favourable agro-ecological conditions for potatoes. The high altitude limited the variety of crops grown in Lelan. Therefore, all farmers in Lelan grew mainly potatoes, whereas those in Saboti and Kaptama had several alternative crops (e.g., maize, beans, cabbages, onions, French beans, carrots, snow peas, garden peas, tea) to grow under the relatively warmer environments. During both the FGDs and the household survey, all farmers in Lelan grew potatoes and very little of other crops (spring onions, cabbage, oats, maize, pears, plums) despite existing potential. According to focus groups in Saboti, maize had taken the place of potato because of the bacterial wilt problem and the low yields realized from potato, which was attributed to low seed quality and poor crop rotation. We could also observe the same trend of increased maize cultivation in Kaptama, and traces of smaller potato fields in Lelan.

Results

Potato Production Calendars

The potato production calendar showed two distinct cropping seasons across wards studied (Supplementary Material 7). All three study sites grew potatoes during both the long and short rainy seasons.

During focus group discussions, participants in the three wards indicated that they prepared potato fields from January to March and planted their potatoes mainly in March and April and August and September for the long and short rainy seasons, respectively. However, some deviations existed depending on weather conditions, altitude, availability of water for irrigation and of seed for planting, such that planting could occur between and during the seasons. Generally, potatoes were harvested from June to August for the

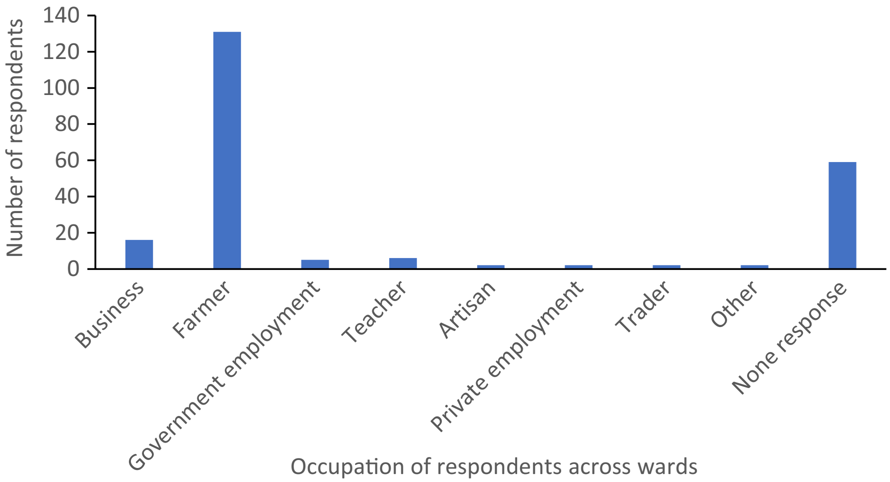

Fig. 2 The main occupation of respondents across study sites

long rainy season crop and in November to December for the short rainy season. However, Lelan at high altitudes tended to have potatoes almost throughout the year.

Importance of Potatoes at Household Level

Most (58.2%) respondents had farming as their main occupation, while the rest were involved in teaching, business, government or private employment, trading and artisan across study sites (Fig. 2). Potato was grown with the main focus as a cash and food crop according to 83.6% and 16.4% of the respondents, respectively (data not shown). The importance of farming in the livelihoods of households was confirmed by 63% of households who derived less than 25% of their household income from off-farm activities (Fig. 3). According to many (48%) respondents, potato

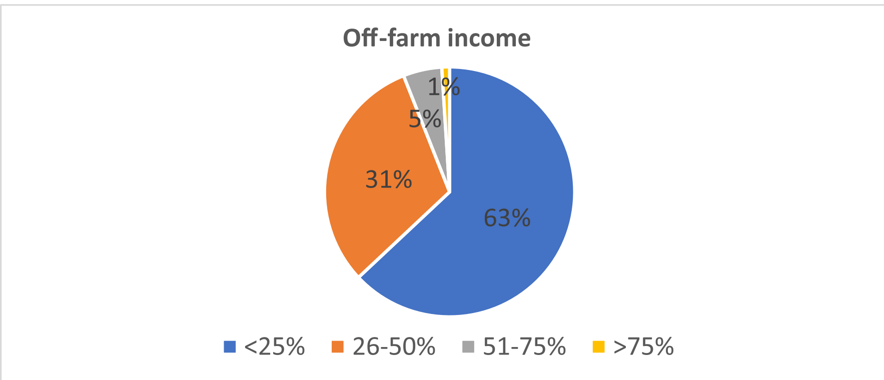

Fig. 3 Contribution of off-farm income to household income across study areas

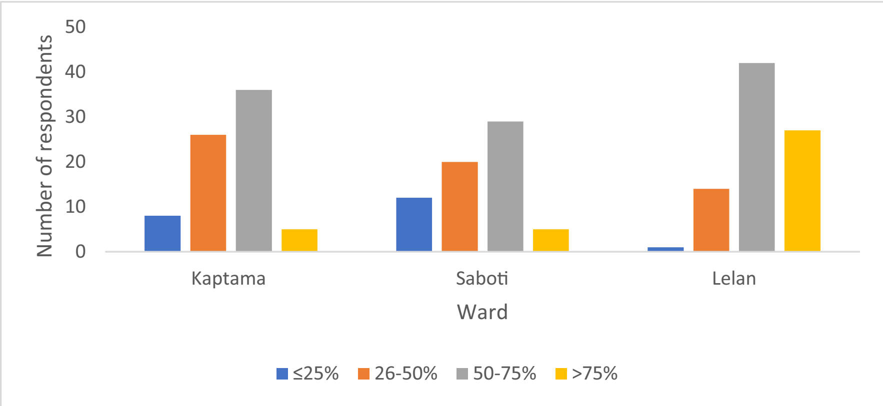

Fig. 4 Contribution of potato incomes to household income in Kaptama, Lelan and Saboti wards in North-western Kenya

contributed 51−75% of farm income across the sites and in each study site (Fig. 4). More farmers received more than 75% of their farm income from potato in Lelan than in Saboti and Kaptama (Fig. 4).

Potato Farming Practices

Most respondents indicated that they had planted potatoes during both the last long (96.4%) and short (92.4%) rainy seasons with more in the long rainy season. However, 100% of the respondents in Lelan indicated that they planted potatoes during both seasons, while more respondents in Kaptama planted in the long rains than in Saboti and vice versa in the short rains (Table 2). Most (90.2%) respondents planted potatoes twice in a year across the study sites, with the highest percentage in Lelan and the lowest in Saboti (Table 2). In Lelan, 14% of the farmers planted three times, and a negligible number of farmers planted only once in a year across study sites. Among the respondents interviewed, 24.9% had access to irrigation across sites; it ranged from 36.9% (Lelan), via 26.7% (Kaptama) to 7.6% (Saboti) (Table 2). In Lelan, the extended growing period niche was evidenced by some potato crop which was being harvested during the time of the FGDs, a time when land preparation and early planting was ongoing in all three study areas.

Major Constraints in Potato Production

During focus groups, participants listed and ranked the major constraints limiting potato production and yields (Fig. 5; Supplementary Materials 8, 9, 10 and 11). Upon synthesis of the ranked constraints, lack of quality seed was ranked the most important constraint according to the different gender groups, followed by diseases (specifically late blight and bacterial wilt combined), and poor marketing (ware pricing), while transportation was the least important. Both men and women had the same perceptions

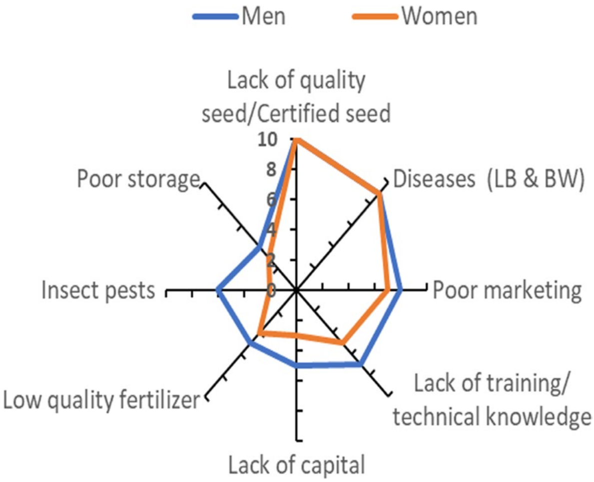

Fig. 5 Radar chart ranking (most important constraint ranked from the outer circle and lowest inside) of farmers' perceptions on major potato constraints in Lelan, Saboti and Kaptama wards, North-western Kenya. LB – Late blight; BW – Bacterial wilt

on the importance of seed quality and diseases. Kaptama was most affected on both seed availability and cost in the long rainy season compared to the other counties.

Analysis of Potato Farming Practices and Their Influence on Productivity

The results presented here show that potato productivity is influenced by farming and crop management practices and can vary depending on the production environment (location, season, management, biotic and abiotic stresses, and socio-cultural factors). The farming and management factors may include varieties grown, seed, fertilizer, crop rotation, and biocide use in insect pest and disease management. The potato sector tends to perform below its potential because of poor production technologies, small and declining farm sizes, and poor crop management practices (Fintrac 2015).

Potato Varieties Planted in the Last Long and Short Rainy Seasons

In their potato growing, most respondents planted the variety Shangi during both the long and short rainy seasons (Fig. 6A, B). All respondents planted predominantly Shangi in Lelan (100%) in both seasons, but in Kaptama 70.7% and 53.3%, and in Saboti 50% and 51.5% during both the long and short rainy seasons, respectively. A smaller percentage of respondents planted other varieties (Arka, Kabale, Kenya Karibu, Kenya Immarika, Markies and Desiree) in Kaptama 24.0% and 33.3%, and in Saboti 42.4% and 37.9% in the long and short rainy seasons, respectively. A combined 12.9 and 23.9% of respondents in Kaptama and in Saboti did not grow any potato variety in the long and short rainy seasons, respectively. Based on their recall, Lelan farmers obtained higher yields than those in Kaptama and Saboti in both the long and short rainy seasons of 2018 (Fig. 7). The overall yield averages obtained

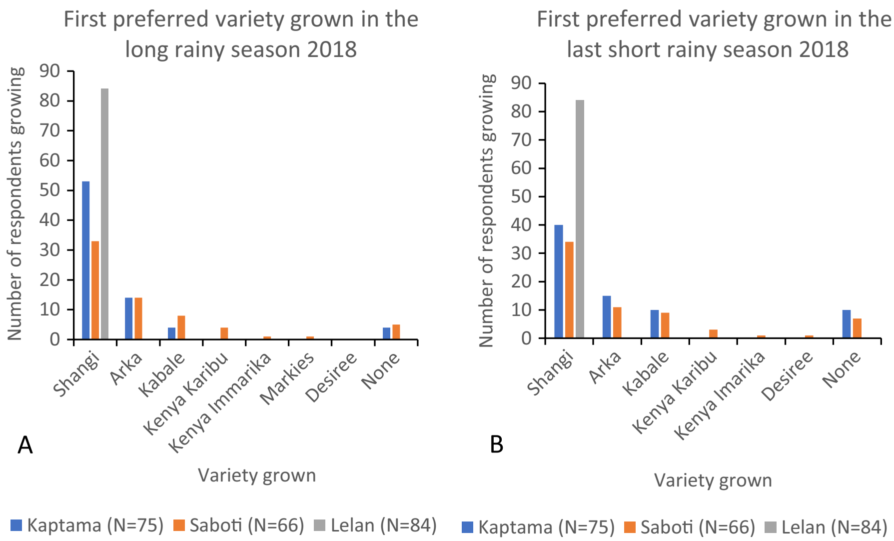

Fig. 6 Potato varieties planted in the last long (**A**) and short (**B**) rainy seasons

in the long and short rainy seasons were 8.8 and 7.7 t ha^{-1} derived from respondent recall estimates based on bags (50- or 100-kg bags) harvested per acre and the ranges were 1.0–24.7 and 1.2–29.7 t ha^{-1} in the long and short rainy seasons, respectively. The mean yields were lower during the short rains in the three wards. During focus group discussions, we observed low yields in some fields (Fig. 8), and one farmer in Saboti remarked that they continued getting low yields because the seed was reused even up to 10 times, and in all counties, participants indicated that there was a tremendous drop in yield compared to earlier years. However, some farmers in Lelan and Saboti claimed they had harvested 70–100 bags per acre (17 – 25 t ha^{-1}) with new seeds in a virgin land.

Fig. 7 Potato yields (t ha^{-1}) harvested estimated from respondents' recall estimates in bags per acre for previous long and short rainy seasons, 2018

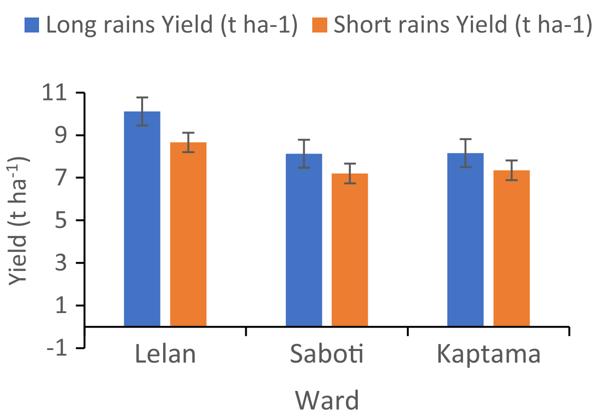

Fig. 8 Farmer with low crop yield harvest in Lelan

Seed Use and Productivity

During both the focus group discussions and the household survey, own saved and neighbours saved seeds were the main types of seed sources used by most respondents during the previous long and short rainy seasons across study sites (Fig. 9). During the long rainy season, 48.0% respondents used neighbours' seed compared to 25.8% in the short rainy season and 57.3% used own saved seed compared to 80.0% in the same seasons, respectively. Only 3.1% respondents across sites accessed certified seed. Over the two seasons, 25.5% respondents purchased or obtained seed from their neighbours regardless of the quality. The seed tuber sizes farmers used varied (small, medium,

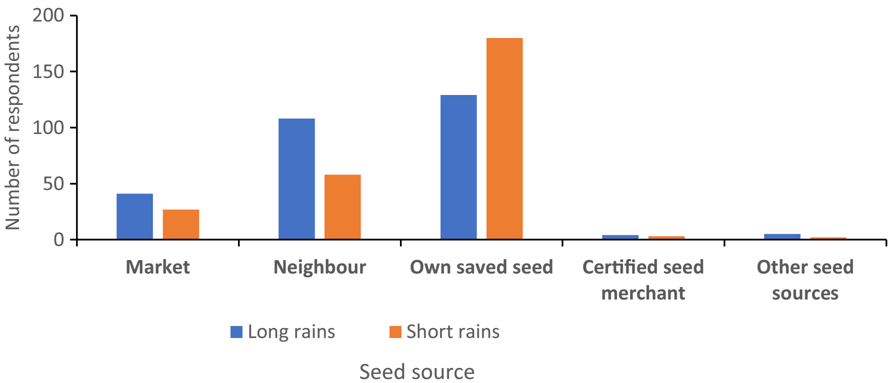

Fig. 9 Sources of seed potato planted in the last long and short seasons, 2018. Certified seed potato merchant = KALRO – Kenya Agricultural and Livestock Research Organization, AGRICO EA Ltd – Agrico East Africa limited, ADC Molo – Agricultural Development Corporation Molo, CIP – International Potato Center)

Table 3 Mean quantity of seed potato planted in kg and 50-kg bags per hectare, median, maximum and minimum used by respondents in the previous long and short rainy seasons of 2018 in Lelan, Saboti and Kaptama in North-western Kenya

Variable	Long rainy season			Short rainy season		
	Quantity of seed (kg ha^{-1})			Quantity of seed (kg ha^{-1})		
	Kaptama	Saboti	Lelan	Kaptama	Saboti	Lelan
Mean	2080 (41.6)	1998 (40.0)	2007 (40.1)	1676 (33.5)	1786 (35.7)	1878 (37.6)
Median	1976 (39.5)	1976 (39.5)	1976 (39.5)	1729 (34.6)	1976 (39.5)	1853 (37.1)
Maximum	3705 (74.1)	2964 (59.3)	3952 (79.0)	2964 (59.3)	2470 (49.4)	3952 (79.0)
Minimum	494 (9.9)	741 (14.8)	988 (19.8)	494 (9.9)	494 (9.9)	741 (14.8)

Figures in parenthesis are the number of 50-kg bags planted per hectare

large), which led to wide variation in the quantities (50- or 100-kg bags or kg) planted per unit area. The quantities of seed tubers planted ranged from 9.9 to 79 bags (50-kg bag) ha^{-1} with an overall mean of 38.1 bags ha^{-1} across study sites (Table 3).

During focus group discussions, some farmers indicated that they sometimes got seed from markets or as gift or donation from other farmers or organizations such as the International Potato Center (CIP) in collaboration with the County State Department of Agriculture in Lelan and the Kenya Agricultural and Livestock Research Organization (KALRO) and the Gesellschaft für Internationale Zusammenarbeit (German: Society for International Cooperation, Ltd (GIZ)) in Kaptama.

There were no local non-governmental organizations (NGOs) dealing with seed potatoes across the study sites. Out of the eleven respondents who had planted certified seed in the past, only four had planted it during the 2018 long and short rainy seasons (Fig. 9). More farmers in Lelan had planted certified seed when compared to Saboti and Kaptama (data not shown). During focus group discussions, it was found that more farmers obtained seeds from the market in Saboti than in Kaptama. Participants in the two wards also indicated that farmers occasionally obtained their seed potato for replacement, which they considered 'clean seed' from Kapcherop in Elgeyo Marakwet County and neighbouring Uganda informally through common border points.

Fertilizer Practice and Productivity

In this study, we found that most farmers used diammonium phosphate (DAP; 18-46-0) at planting during both long (81.6%) and short (74.2%) rainy seasons (Table 4). Other fertilizers used at planting by a few farmers were Baraka (13-25-15+S+CaO+MgO+Zn+B) and compound 23-23-0. Over 60% of the farmers did not top-dress their potatoes. However, for those who did, CAN (64%) was commonly used and in some cases Urea (20%), minimal Baraka (18-0-21+S+CaO+MgO) top dress, with the majority (61.7%) using diverse foliar fertilizers as an alternative top dress to boost their potato production. The quantities of the different fertilizers used by most farmers in each season were below the

Table 4 Farmers' responses on the use of planting and top-dressing fertilizers and their quantities* per hectare in potato growing based on recall of individual farmers for last long and short rainy seasons

Type of fertilizer used	Number of respondents using fertilizer (*N*=217)	Quantity (kg ha^{-1}) of fertilizers used			
		Mean	Median	Maximum	Minimum
Planting fertilizer					
Diammonium phosphate (*N*=217)	177 (81.6%)	214.8	185.0	618.0	124.0
Planting fertilizer: 23-23-0 (*N*=217)	6 (2.8%)	135.9	123.5	247.0	61.8
Baraka fertilizer (*N*=217)	38 (17.5%)	206.0	124.0	371.0	124.0
Other: Farmyard manure, Latchland, Mavuno *N*=217)	16 (7.4%)	322.2	370.5	741.0	9.9
Top dressing fertilizer					
Calcium ammonium nitrate (*N*=217)	64 (29.5%)	187.7	182.7	494.0	30.0
Urea (*N*=217)	20 (9.2%)	124.8	120.6	247.0	30.0
Baraka top dressing fertilizer (*N*=217)	2 (0.9%)	247.0	247.0	247.0	247.0
Foliar feed – 139 (217)	139 (64.1%)				
Other Latchland top dressing (*N*=217)	2 (0.9%)				

*The quantities of inputs were given in different units; fertilizer in 50-kg bags per acre and insecticides and fungicides as 1st, 2nd or 3rd preferred types. Majority of respondents had the 1st preference shown above. **Frequency of pesticide application in each season is shown in Fig. 12

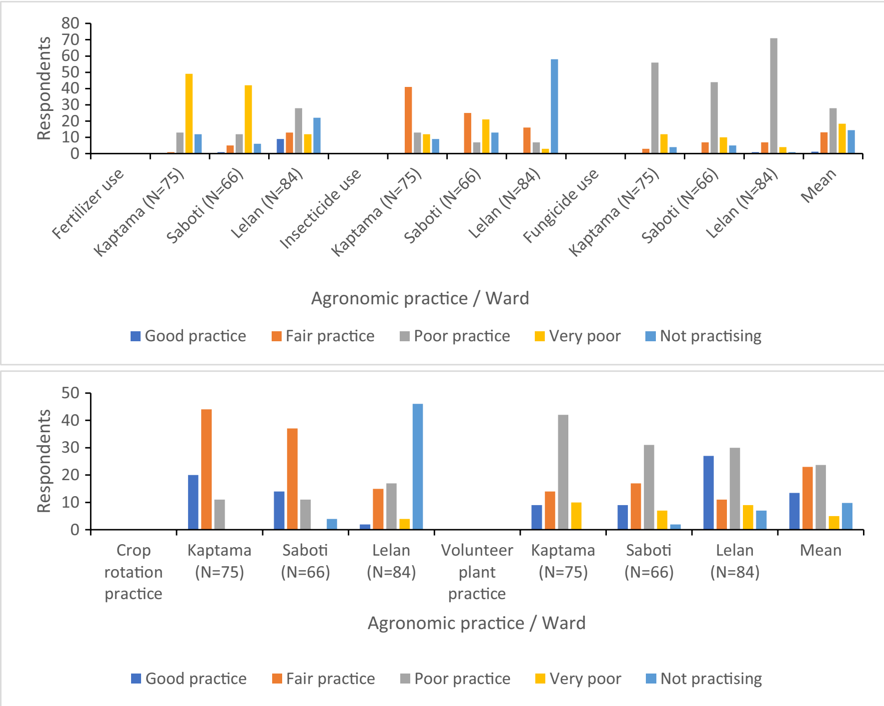

Fig. 10 Common agronomic practices in potato production during the long and short rainy seasons of 2018 as charged by the investigators based on responses of respondents in Kaptama, Saboti and Lelan wards. The determination of the level of farmer practice based on scientists' judgment according to quantities and combination of fertilizer used, type and frequencies of insecticides used, frequency of potato in a rotation sequence in one to 4 or 5 seasons and volunteer practice as in Table 8

nationally recommended levels as indicated by respondents across the study areas. The quantities of DAP and CAN used by the different respondents varied from 124 to 618 kg ha^{-1} and 61.8 to 494 kg ha^{-1}, respectively (Table 4), with very few farmers applying the upper limits. There seemed to be more farmers practising fertilizer use in Lelan than in Kaptama and Saboti (Fig. 10). More farmers had fair (application of 245 – 449 kg planting fertilizer + ≥ 200 kg top dressing fertilizer ha^{-1}) to good (at least 450 kg planting fertilizer + >200 kg top dressing) fertilizer practice in Lelan compared to Kaptama and Saboti (Supplementary Material 3). Generally, most respondents had very poor (1 − 144 kg planting fertilizer + ≤ 99 top dressing fertilizer) practice, especially in Kaptama and Saboti.

The relationship between yield and fertilizers alongside other parameters was examined using a correlation matrix (Table 5; Supplementary Materials 4 and 5). There was a weak (R=0.226) and moderate (R=0.385) positive correlation between fertilizer use and yield for the long and short rainy seasons, respectively. Fertilizer use and altitude showed a strong (R=0.500) positive correlation (Table 5). Most respondents used foliar fertilizers as top dress supplements, which showed a weak positive correlation

Table 5 Correlation between common agronomic farmer practices and potato yield estimated by farmers in bags (50- or 100-kg bag) harvested per acre (converted to hectares) in the long and short rainy seasons of 2018 across Kaptama, Saboti and Lelan wards. *CRP* crop rotation practice, *FP* fertilizer practice, *FUNGP* fungicide use practice, *INSECP* insecticide use practice, *FFP* foliar fertilizer use practice, *VPP* volunteer plant practice, *FAP* farmer agronomic practice, *YLD_LR* average potato yield (t ha^{-1}) in the long rainy season of 2018, *YLD_SR* average potato yield (t ha^{-1}) in the short rainy season of 2018, *FAP* farmer agronomic practice

	CRP	FP	FFP	FUNGP	ISECTP	VPP	FAP	Altitude	YLD_LR	YLD_SR
CRP	-									
FP	**-0.379**	-								
FFP	-0.150	**0.545**	-							
FUNGP	-0.134	**0.251**	0.127	-						
ISECTP	**0.293**	-0.079	-0.055	0.082	-					
VPP	-0.076	-0.017	-0.039	-0.114	0.029	-				
FAP	**0.303**	**0.313**	**0.315**	**0.491**	**0.763**	0.183	-			
Altitude	**-0.696**	**0.500**	**0.266**	0.186	**-0.374**	0.078	-0.181	-		
YLD_LR	-0.210	0.226	0.138	0.104	0.046	0.178	0.141	**0.231**	-	
YLD_SR	-0.103	**0.385**	**0.283**	0.082	0.136	0.105	**0.281**	0.182	**0.476**	-

Critical levels for |r| at $n = 225$ are 0.138 for $P = 0.05$; 0.181 for $P = 0.01$ and 0.229 for $P = 0.001$. *R* values in boldface indicate moderate or strong correlations between common agronomic farmer practices or factors and are significant correlations at $P \leq 0.001$

with yield and a better correlation in the short rains (R=0.283) compared to the long rains (R=0.138) (Table 5).

Pest Management, Biocides Use and Productivity

Potato farmers were facing several insect pests and diseases, which they must manage (Fig. 11). Kaptama and Saboti experienced more insect pests compared to Lelan, where cutworm and potato tuber moth seemed to be more common. Potato cyst nematode was not known by farmers but only 2.8% of respondents indicated they had experienced root knot nematodes in Kaptama and Saboti as guided by the photograph. Most respondents in Lelan did not use insecticides, however, fair practice (one insecticide + 3 sprays or two insecticides + 4 sprays) was common in all sites (Fig. 10; Supplementary Material 3). The most used insecticides were Lambda-cyhalothrin 17.5 g/l (Duduthrin) (36.4%), Alpha-cypermethrin (Alpha tata / Alpha cymba) (19.3%) and Lambda-cyhalothrin 50 g/l (Pentagon) (3.7%) (Supplementary Material 12). Most (62.2%) respondents had more insecticide sprays in the short rains than in the long rains, and more fungicide sprays in the long rains than in the short rains. In Lelan, more farmers did not use insecticides compared to Kaptama and Saboti (Fig. 10). However, more farmers had fair insecticide practice in Kaptama and Saboti.

According to focus group participants, late blight (LB) and bacterial wilt (BW) were the major potato diseases known to farmers, with BW being the greatest challenge, particularly in Saboti and Kaptama compared to Lelan. Late blight was indicated as critical during the long rains and BW during the short rains in all study sites. Late blight disease was experienced by more respondents in Lelan compared to Saboti and Kaptama. Few respondents indicated early blight and viruses being a problem. Farmers had limited options for the control of BW with some of them opting to grow more maize than potato. Biocide use was found to be common,

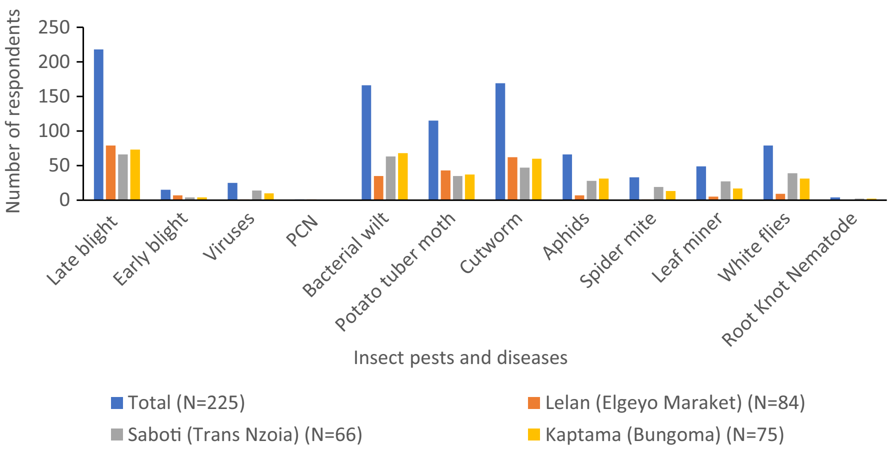

Fig. 11 Common insect pests and diseases in potato production in the last two seasons during household survey

Table 6 Number of respondents using insecticides and fungicides in potato production in the long and short rainy seasons of 2018 in Kaptama, Saboti and Lelan

Pesticide type	Long rainy season			Short rainy season			Overall percentage
	Kaptama (*N*=75)	Saboti (*N*=66)	Lelan (*N*=84)	Kaptama (*N*=75)	Saboti (*N*=66)	Lelan (*N*=84)	
Insecticide type 1 (*N*=144)	66 (88%)	53 (80.3%)	25 (29.8%)	47 (62.7%)	45 (68.2%)	58 (69.0%)	66.3
Fungicide type 1 (*N*=215)	70 (93.3%)	62 (93.9%)	83 (98.8%)	65 (86.7%)	59 (89.4%)	77 (91.7%)	92.3

and fungicides were used by more respondents (92.3%) than insecticides (66.3%) (Table 6). The results showed that respondents rarely used more than one of the common fungicides or insecticides in the control of late blight and insect pests, respectively. The common fungicides were Cymoxanil 8% and Mancozeb 64% (Mistress) (71%), Metalaxil-M (Ridomil) (8.8%), Mancozeb 80% (Oshothane) (6%), and Mancozeb 800 g/kg (Milthane Super) (3.7%) in that order (Supplementary Material 13).

Many respondents used one insecticide or fungicide in their spray programme, with systemic fungicides more commonly used than preventive types. The number of sprays applied by respondents during the long and short rains of 2018 varied from 1 to 8 and 2 to 10 for insecticides and fungicides, respectively (Fig. 12A–D). Most respondents (76%) had poor fungicide use (one fungicide + 4 − 5 sprays or two fungicides + 5 sprays) across the study sites (Fig. 10), based on the need for alternate spraying. Farmers used one to more fungicides once to more than 5 times in the control of LB with no established spraying regime. Although most respondents across sites did not use fungicides rationally, Lelan had more farmers with good fungicide practice (one fungicide + 1 − 2 sprays or two fungicides + 3 sprays) and was comparable to Kaptama on fair fungicide practice (one fungicide + 3 sprays or two fungicides + 4 sprays) (Fig. 10; Supplementary Material 3).

There was almost no (R=0.046) correlation between insecticide practice and yield in the long rainy season and a weak (0.136) positive correlation in the short rainy seasons (Table 5). However, there was a strong (R=0.763) positive correlation between insecticide use and overall farmer practice, positive with all other inputs

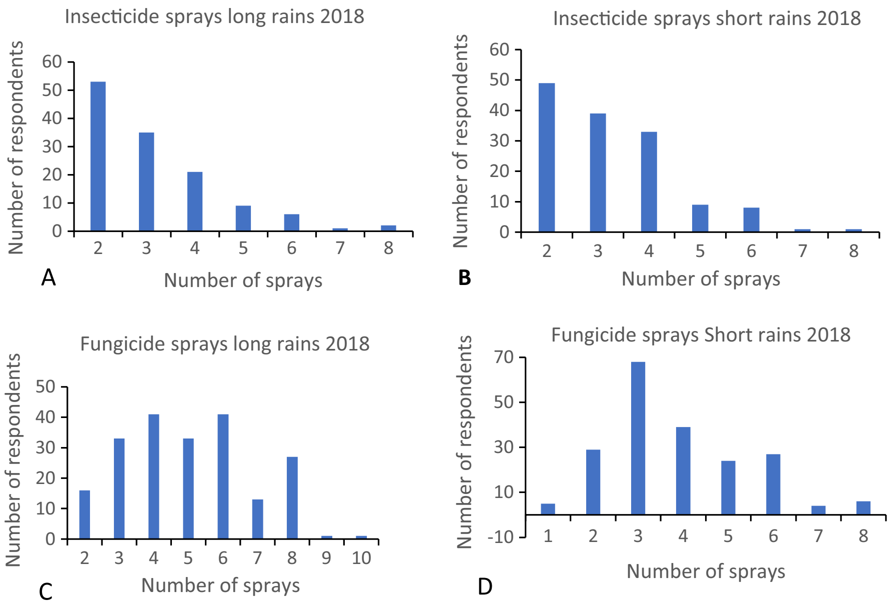

Fig. 12 Number of insecticide (**A**) and (**B**) and fungicide (**C**) and (**D**) sprays and number of respondents practising in long and short rainy seasons of 2018 across survey sites

Fig. 13 Relay cropping of potato and maize in Saboti

but a moderate (R=−0.374) negative correlation with altitude. Overall/farmer agronomic practice was derived by calculating the mean score of each practice category; fertilizer, foliar fertilizer, insecticide, fungicide, crop rotation and volunteer plant treatment use or practice.

There was a moderate (R=0.491) positive correlation between fungicide practice and overall or farmer agronomic practice but a weak (R=0.186) positive correlation with altitude and yield during both the long (R=0.104) and short (R=0.082) rainy seasons.

Crop Rotation Practices and Productivity

Although potato was mainly grown as a monocrop, some farmers occasionally intercropped it with other crops or practised relay cropping (Fig. 13), mainly in Kaptama and Saboti. Regarding crop rotation, 77.8% of the respondents across study sites indicated that they practised crop rotation (Table 7). However, there were variations among respondents with more of them practising crop rotation in Kaptama and Saboti than in Lelan, where more farmers did not practise crop rotation (Fig. 10). Also, the farmers followed varied rotation sequence practices of potato and other crops as defined in Table 8. During focus group discussions, the common crops grown by

Table 7 Number of respondents practising crop rotation in potato growing

	Crop rotation	Number of seasons of crop rotation*
Saboti (N=66)	62 (93.9%)	
Kaptama (N=75)	75 (100.0%)	0 to ≥4
Lelan (N=84)	38 (45.0%)	
Total (N=225)	175 (77.8%)	

*There were inconsistencies in number of seasons of crop rotation depending on land size, individual farmer, availability of seed and altitude (location)

Table 8 Ranking of common crop* rotation practices based on the frequency of potato in the cropping sequences in five seasons according to respondents in Saboti, Kaptama and Lelan

Rank	Crop rotation practice	Frequency of potato in five seasons
4	Good practice	One potato crop in five seasons
3	Fair practice	Two potato crops in five seasons
2	Poor practice	Three potato crops in five seasons
1	Very poor practice	Four or five potato crops in five seasons
0	Do not practise	Do not practise

farmers, which made rotation convenient, included maize, beans, cabbages, carrots, garden peas, snow peas, onion, oats and wheat in Kaptama and Saboti. In Lelan, crops occasionally grown in rotation with potatoes included cabbage, oats and maize or fallow for farmers with larger farms. Potato frequency in the crop rotation was reasonably low (two potato crops in five seasons) among respondents across study areas (Fig. 10). Lelan showed better yields with a difference of 2.0 and 1.5 t ha^{-1} in the long and short rains with or without crop rotation or other practices compared to Kaptama and Saboti, respectively (Fig. 7). There was a strong (R=−0.696) negative correlation between applying crop rotation and altitude (Table 5). Generally, crop rotation showed a negative correlation with most parameters measured and a weak positive correlation with insecticide (R=0.293) and overall farmers' agronomic practice (R=0.303).

Treatment of Volunteer Plants

Most respondents retained potato volunteer plants for food (64.0%) and others for both food and sale (55.1%) (Table 9). Although more farmers in Lelan retained volunteer plants for food than farmers in Kaptama and Saboti, a larger number of them removed them, showing a good practice. Treatment of volunteer plants showed a

Table 9 Management of volunteer potato plants among respondents

Volunteer plant management practice	Number of respondents (N=225)
Retain and harvest for food (N=225)	144 (64.0%)
Retain and harvest for food and sell (N =225)	124 (55.1%)
Remove by uprooting/digging out (N =225)	87 (38.7%)
Other practices:	
None (N =225)	191 (84.9%)
Use as seed (N =225)	29 (12.9%)
Uproot when cannot grow with other crops (N =225)	2 (0.9%)
Uproot only when thinning (N =225)	1 (0.4%)
Uproot when growing with onions (N =225)	1 (0.4%)
Uproot excess plants close to the maize (N =225)	1 (0.4%)

weak positive correlation with altitude and yield in both long and short rainy seasons. Overall, respondents had fair (average) agronomic practices, followed by poor (much below recommended) agronomic practices and good (recommended) agronomic practices or did not practise (Fig. 10). Kaptama and Saboti showed better agronomic practice than Lelan, however, to the contrary Lelan had higher yields by 1.75 t ha^{-1} (Fig. 7). The variations among the study sites and correlations between measured variables support the hypothesis that "potato farming and management practices influence potato performance and can depend on production environment."

Ridging and Weeding Management

Farmers commonly planted potatoes in furrows on flat ground and ridging or earthing up was done later after emergence during weeding. According to participants across the counties, weeding was carried out manually using a hoe (*jembe*), by family or hired labour at varied costs with no herbicide use. Participants during FGDs indicated that weeds were more problematic and costly in Lelan compared to Saboti and Kaptama with farmers using imported labour from as far as Uganda.

Harvesting Practices

The common practice across the study areas was harvesting potatoes without hardening with a hand hoe (*jembe*), whenever a buyer was available. In order to understand farmers' practices and perceptions on harvesting potatoes, they were asked how they decided when to harvest their potato crop, with each criterion considered individually. Farmers used different criteria to decide when to harvest potatoes (Supplementary Material 14). Most (87.6%) respondents indicated that they harvested at maturity when the leaves had turned colour but without cutting the tops or dehaulming. However, others indicated that they harvested at maturity when the leaves had dried up (70.2%) or when leaves were still green without dehaulming among other practices. Other respondents (14.7%) cut back or dehaulmed, while 4.9% of respondents indicated that they dehaulmed potatoes only when they were harvesting for seed tubers, which was also indicated during the focus group discussions. Generally, harvesting potatoes was done without a standardized grading but based on the farmer's or buyer's perceptions depending on the availability of ware potatoes but not the recommended practice. Some farmers retained their potatoes in the field for even more than one month, especially in Lelan when prices were bad, a practice which led to the sprouting of the tubers in the field (see Fig. 14A and B). They allowed the crop to be covered by weeds which they said provided some cooling effect, where one farmer said of a common *Brassica sp*. "the weed acts as a refrigerator to the potato tubers", hence staying for longer duration in the field to await prices to improve.

The common practice across the three sites studied involved harvesting potatoes by hand hoe (*jembe*). Focus group participants indicated that they either selected seeds from their harvests or left a section of the crop in the ground for a while before harvesting as a form of in situ seed storage for the long rainy season planting. A small number of farmers set aside part of their crop and dehaulmed early for seed.

Fig. 14 **A, B** Sprouting of tubers in a delayed harvested crop of Shangi (*left*) and packaged potatoes for direct sale at the farm (*right*) in Lelan ward

Also, the smaller tubers were left on top of the ground in the field after harvest and were later collected for seed, a practice that was common across study sites.

In Saboti and Kaptama, there were diversified traders who supplied potatoes to consumers in surrounding towns and commercial centres such as Kitale, Kiminini, Kimilili, Kamukhuiwa, Bungoma town and even Chwele on bicycles, motorcycles, public service vehicles and pickups with fewer restrictions on the varieties grown. Among the widely grown varieties, Kabale and Arka are red in colour, but respondents indicated that they were equally sold with ease, although Shangi was the most preferred. On the other hand, brokers worked with transporters to supply the three potato varieties to distant markets in Mombasa, Nairobi, Nakuru, Kisumu and Uganda with Shangi being the most popular variety.

Table 10 Different channels of extension respondents use to access information on potato production

Channel of access to extension information	Number of respondents
Family members or neighbours (*N*=225)	209 (92.9%)
Radio (*N*=225)	93 (41.3%)
Extension field visits by county agriculture officers (*N*=225)	53 (23.6%)
Field days (*N*=225)	50 (22.2%)
Agricultural shows (*N*=225)	21 (9.3%)
Television (*N* =225)	13 (5.8%)
Mobile phone applications (*N* =225)	8 (3.6%)
Extension leaflets and brochure (*N* =225)	6 (2.7%)
Exhibitions (*N* =225)	6 (2.7%)
Newspapers/newsletters (*N* =255)	5 (2.2%)

Channels of Access to Extension Information on Potato Production among Farmers

Most respondents indicated that they accessed agricultural extension information from family members or neighbours/other farmers (92.9%) (Table 10). They also indicated radio, extension visits by county agricultural officers, field days and agricultural shows, in that order of importance, as other channels of getting agricultural information.

Limitations

A few limitations to the survey data analysis and interpretation of results were identified.

- The study relied heavily on farmers' recall ability and honesty, with limited verifications through observations where possible.
- The measure of yield (productivity) collected in the survey was less reliable due to response bias and potential inaccuracy of farmers' estimations of their yields and areas planted. Accurate measures of yield would require primary data collection through approaches such as crop cutting, as discussed in the "Farmers' Perceptions on Potato Yields" section.
- Respondents provided incomplete rankings of the list of options for certain questions provided, which gave a challenge in data analysis on some of the questions. Thus, we used the most ranked options.
- Although differences in cultures and in-depth socio-economic status among the communities interviewed in each site existed, which could influence their farming practices, preferences and eating habits, it was beyond the scope of this study.

Discussion

Farmer Characteristics

The high percentage of respondents being less than 45 years in age indicated that a high proportion of the farmers belonged to the active-youthful population bracket among the communities interviewed, which could enhance potato farming through ease of acquired skills and the use of modern technology (FAO 2017). Young and middle-aged farmers are mostly receptive to adopt new technologies in farming (Fintrac 2015; Waswa et al. 2021). Also, 95.5% of respondents with at least primary education showed that farmers had some literacy, which could help them learn potato and other agricultural farming practices. The high percentage of respondents who are non-smart phone and smart phone owners in Lelan compared to Saboti and Kaptama could be attributed to the economic ability afforded by more potatoes grown in Lelan than in Saboti and Kaptama. This indicated that with motivation in the use of relevant social media programmes with economic empowerment through better potato prices the farmers could easily access agricultural information online. Krell et al. (2020) found that smart phone owners in Central Kenya were more likely to use mobile phone services for farming than non-smart phone owners. There was a big potential for use of social media as a means to boost agricultural information sharing, which was handy for the majority of the youthful farming population. Knowledge about the farmers and their socio-economic status helps in both desegregation of farmers for better targeting and technology adoption (Waswa et al. 2021).

The small land sizes (< 2.025 hectares) planted with potatoes showed that most farmers were small scale, particularly in Saboti and Kaptama. However, Lelan with larger land sizes under potato showed that with good agricultural practices, there was capacity to grow more potatoes, and particularly for seed multiplication, than in Saboti and Kaptama, which have limited land sizes for rotation and isolation. The farming communities relied heavily on farming for their livelihoods, which suggests a need for improved practices for increased productivity but also considerations for other income-generating enterprises including agro-processing of potatoes. This was strongly supported by the low contribution of off-farm household income as confirmed by the limited livelihood occupation engagements among the community members.

Farming Practices

The limited access to other sources of income and the high contribution of potatoes to farm income made it the main focus as a cash crop and source of livelihood for households across the study areas (Fig. 4). The high percentage of farmers growing potato for cash supports previous findings (Muthoni et al. 2013; Fintrac 2015). Although potato was grown mainly during the two main cropping seasons, a third or fourth crop cycle was possible through staggered or overlapping periods of planting and harvesting, particularly in Lelan. This was afforded by relatively favourable weather conditions in the cool high altitudes and possibly conducive soil conditions (personal observation by the first author) but in Kaptama and Saboti mainly with supplemental irrigation. The study areas had low access to irrigation, which implies that farmers relied heavily on rain-fed agriculture. However, the development of irrigation facilities was feasible particularly in Lelan and Kaptama since natural water sources were observed, from which some farmers practised supplemental overhead irrigation facilitated by gravitational force.

In East Africa, two or three growing seasons per year supply the market with fresh potato almost all year round (Gildemacher et al. 2009; Janssens et al. 2013; Haverkort and Struik 2015). Through observations it appeared that there were additional cropping cycle(s) potentials with judicious use of the seasons, irrigation and early maturing varieties. Haverkort and Struik (2015) raised the importance of matching the variety growth cycle with seasonal length. Kolech et al. (2017) reported four distinguishable seasons in North-western Ethiopia, which were exploited by farmers for potatoes. In the areas studied, Saboti and Kaptama were limited to two times of planting because of restrictive weather conditions, which tended to have early and longer drier periods compared to Lelan during and between the short and long rainy seasons.

The high percentage of farmers planting potatoes each season was a clear confirmation of the importance of potatoes in the study areas, particularly in Lelan, where 100% of the respondents planted the crop during both the long and short rainy seasons (Table 2). The differences between Kaptama and Saboti in the planting of potatoes were marginal, indicating similarity in potato farming behaviour for example in varieties grown, possibly because the two wards were relatively close to each other, and had near similar agro-ecological conditions compared to Lelan. However, the variety Shangi was predominant across sites as a result of high market demand, but Kabale and Arka were relatively popular in Kaptama and Saboti, possibly because they had a market niche for these varieties, which Lelan lacked.

Farmers' Perceptions on Potato Yields

The farmers' perception during focus group discussions that there was a continuous decline in potato yields and the low yields obtained during household survey confirm the view that Kenya is characterized by low and declining crop productivity (Kabubo-Mariara and Kabara 2018). Nyankanga et al. (2004) reported that farmers use potato varieties without adequate seed replacement, which resulted in low yields and the accumulation of viral diseases in seed stocks. Recycling of seed even up to 10 times, as indicated by farmers, reveals the low-quality seed commonly used, which could be attributed to a possible lack of robust approaches to renovating seed. The overall yield averages of 8.8 and 7.7 t ha^{-1} in the long and short rainy seasons, respectively, were closely comparable to the national average yields (7.7 t ha^{-1}) (Janssens et al. 2013; Muthoni et al. 2013; Waswa et al. 2021), and likewise the ranges 1–24.7 and 1.2–29.7 t ha^{-1}. However, the extremely low yields could have been a result of farmers providing unrealistic figures, which sometimes occurs due to social reasons or under-/overestimation. Janssens et al. (2013) reported cases of yields below 3 t ha^{-1}, which they attributed to poor agronomic practices, low use of inputs, especially fertilizers and fungicides, low soil fertility and limited access to quality seed, as confirmed in the current study.

Although the use of farmer recall for data collection could be less reliable, the data provide useful information, which explain farmers' situations and practices. Systematic errors in data from in-person household surveys are common (Kasprzyk n.d.), and grossly underestimated potato yields have been reported to give inconsistent statistics (Gildemacher et al. 2009; Fintrac 2015), part of which is attributed to the variation in the bag sizes used for ware potatoes (Fintrac 2015). For verification, research is needed on actual yields through crop-cutting method (Lobell et al. 2019; Blatchford et al. 2019), weighing the number of units farmers harvest (Fermont and Benson 2011) or survey test digs and harvest observation (Oliveira et al. 2016). This is critical because in many instances farmers still sell potatoes using an extended bag (Fintrac 2015; Waswa et al. 2021).

The constraints and factors contributing to the decline in yields (Fig. 5) suggest intervention points for improved yields. The wide variation in potato yields provides targets for improved agronomic practice and a stimulus to improve varieties to increase production (Birch et al. 2012). However, despite the variation in yields, there is still a large yield gap to close. Although we did not study the socio-economic situations of the farmers, we understand they do influence the farmer's management practices. Some possible socio-economic factors that could be contributing to the low potato yields include lack of training/technical knowledge, lack of capital/cash or capacity to invest/credit, exploitative nature of the market particularly during the main harvesting period and the price fluctuations, which may range from KShs. 400 to over KShs. 3000 per extended 50-kg bag depending on supply and the market players. The low prices farmers get on most occasions render them unable to raise sufficient cash to acquire the right inputs and quantities for recommended practices. It needs to be determined if farmer education would lead to greater demand for seed and other inputs and also if demand could be met by suppliers and if farmers could access credit.

Potato Management practice

Seed Use and Management

Yield and performance depend on crop management (Haverkort and Struik 2015). Addressing identified limiting practices will go a long way in meeting the objectives set in the National Potato Development Strategy 2016–2020 (MoAL&F 2016). Access to seed potatoes, their sources and replacement frequency have a great bearing on success in potato production and productivity. Seed potato tubers are prone to disease infections some of which are latent (Kassa and Chindi 2013), implying that an ordinary grower may not be able to know the quality status of the seed they use. Using certified seed is one way to ensure seed quality; however, such seed was not easily accessible to farmers in the production areas and if available was expensive for the smallholders. The problem of seed seems to be strategic from the side of the formal seed system since there were more seed merchants during the time of study compared to five years earlier (NPCK 2017). The situation left farmers to rely on their own farm-saved seed or neighbours and markets, where quality is always low and not easy to ascertain.

Over 90% of farmers use informal seed sourced from retained harvest, exchange with neighbours or purchased from markets (FAO 2013; Fintrac 2015). The reliance on farm-saved seed has lived on for many years according to previous studies (Durr and Lorenzl 1980; Crissman et al. 1993; Kaguongo et al. 2008; Gildemacher et al. 2011; Kwambai et al. 2011; FAO 2013; Kaguongo et al. 2013; Muthoni et al. 2013; Fintrac 2015; Mburu et al. 2020), suggesting that there was a need for sustainable approaches to the problem such as availing seed within reach of farmers at affordable prices. The higher use of neighbours' seed by 48.0% of the respondents in the long rainy season than in the short rainy season (25.8%) showed that many farmers were unable to store their own seed between the long period between the short and long rainy season. However, they could easily use their own seed as practised by 80.0% of the respondents in the short rainy season planting afforded by short dormancy cultivars such as Shangi soon after harvesting the long rainy season crop**.**

The lack of farmers' involvement in the formal seed system and limited awareness of the existing seed agencies among respondents imply that the use of informal seed sources will continue to dominate. Thus, low yields and the inevitable spread of diseases will persist, unless urgent interventions are put in place. Generally, recycling of seed contributed to seed degeneration (Thomas-Sharma et al.

2015; Navarrete et al. 2022), and coupled with a lack of crop rotation, aggravated build-up in and spread of insect pests and diseases. Seed degeneration is defined as a decreased quality of seed tubers by build-up of pathogens and pests from continued propagation over time (Struik and Wiersema 1999; Priegnitz et al. 2018). Most potato growers lack proper information on and training in seed selection (Fintrac 2015). Seed quality management goes beyond following technical knowledge and prescriptions: it requires collective action (Tadesse 2017).

According to focus group participants, farmers prefer getting seed from other farmers or using their own seed but from different field(s) with the notion that seed from another field would perform better in a different field, which they say, "it was not used to". Farmers from both Kaptama and Saboti occasionally obtained their seed potato for replacement from Elgeyo Marakwet and neighbouring Uganda, where they risked the spread of insect pests and diseases. However, the practice led to the introduction of the variety Kabale, which was still new but was diffusing fast in Kaptama and Saboti. This indicated that farmers were aware of the need to replace old seed and varieties but lacked access to quality seeds and the capacity to ascertain the quality of the perceived "new" and/or "clean" seed from informal sources. Crissman et al. (1993) reported the existence of well-established informal seed flows for potatoes in Meru, which did not exist in the three areas studied. Accessing seed from Elgeyo Marakwet county by farmers in Kaptama and Saboti points to the benefit of high altitude in seed potato production, which could be exploited in the informal seed system if farmers were trained in collective seed health management to avoid disease spread. Abdurahman et al. (2019) found a 96.6% bacterial wilt incidence in a recipient village of newly introduced varieties compared to 0.06% in a non-recipient village in Uganda.

Kaptama was most affected by seed unavailability for the simple reason that not all seed preserved in November/December reaches the next planting season in March/April due to poor storage facilities and short dormancy. The quantity of seed used per unit area planted varied widely possibly because of the varied seed tuber sizes or under-/overestimation by respondents (Table 3). However, the mean reflected the limits within the recommended rate, which suggests that if farmers had quality seed and practised good agricultural practice in their potato crop management, they could achieve high yields. Although we did not ask respondents about their willingness to purchase seed potatoes, the 25.5% of the respondents who purchased or obtained seed from their neighbours gave an indication that a quarter of the farmers could be willing to purchase seed. In general, there is a need to investigate further the actual willingness to seed purchase and for deliberate efforts to supply quality seed potatoes and train farmers in seed management towards increased potato production in each production area.

The growing of certified seed far away from North-western Kenya, the lack of an effective seed distribution system, high seed prices and inadequate knowledge on and experience in the use of quality seed were the main reasons for the lack of its access. The low prices of ware potatoes render farmers unable to purchase certified seed and other recommended inputs even if they were available. In some cases, even those who may purchase certified seed would always buy small quantities because of limited cash or fear of risks on the unreliable ware prices. However, such purchase would provide opportunities for renovating seed in the subsequent season(s). Potato benefits those who are in the marketing part of the potato value chain at the expense of the farmers who have little influence on the pricing.

Fertilizer Use Practice and Potato Productivity

Low soil fertility is a limiting factor in smallholder farms (Gildemacher et al. 2009; Muthoni et al. 2013; Fintrac 2015), which calls for soil fertility management through improved farming practices and fertilizers use. Farmers use mainly DAP fertilizer at planting and CAN for top dressing, possibly because of their long-time use and existing recommendations, easy access and limited exposure and access to other types of fertilizers. Kaguongo et al. (2008) reported that most (96%) farmers used DAP, and few (8%) used CAN in potatoes in Kenya, which agreed with our findings. Farmers used low quantities of the fertilizers compared to the general recommended rates for DAP (90 kg P_2O_5 ha^{-1}; 500 kg ha^{-1}) and CAN (78 kg N ha^{-1}; 300 kg ha^{-1}) for potato growing in Kenya (Kabira et al. 2006; Gildemacher et al. 2009; Kaguongo et al. 2008). This was mainly attributed to the high cost of fertilizers and the inadequate knowledge and experience farmers had on the significant gains optimum quantities of fertilizer use had on potato performance, particularly in Saboti and Kaptama. The application of less than half of the recommended rate of DAP and CAN by most respondents could be contributing to the low yields widely realized among farmers. This was even more critical since most soils in the region were reported to generally have low fertility (Muthoni and Nyamongo 2009). Wang'ombe and van Dijk (2015) found that only 18% of farmers interviewed in three counties used recommended quantities of fertilizers, compared to 4.1% of the respondents who applied the recommended rate of DAP among 81.6% among those interviewed across the survey areas. Also, continuous cultivation with little application of manure or fertilizer contributes to a decline in soil fertility and yields in most areas (Kabira et al. 2006; Fintrac 2015). Better use of fertilizer and other farmer practices in addition to favourable environment and possibly better seed in Lelan could have contributed to higher yields than in Kaptama and Saboti (Fig. 7).

The highly significant, strong and weak positive correlations between fertilizer use (R=0.500) and foliar fertilizer (0.266) with altitude, respectively, showed that more farmers in Lelan (high altitude) used fertilizers more than those in Kaptama and Saboti (low altitude) (Table 5), possibly because of increased reliance on potato with the rise in altitude. The weak and moderate positive correlation between fertilizer use and yield in the long (R=0.226) and short (R=0.385) rainy seasons, respectively, indicated that the use of higher quantities of fertilizers could result in increased yields. The varied management practices and environments under which the potatoes were grown could have contributed to the inconsistencies in yields. Also, the poor fertilizer practice in Kaptama and Saboti could be a key factor for the low yields realized. While working on intensive management of variety trials, Komen et al. (2017) found that by the employment of good agricultural practices both local and new Dutch varieties were comparable in their yield performance with a yield increase of over 70% among the local varieties.

Insect Pest and Disease Management and Biocide Use

Many factors influence insect pest and disease incidences and spread, which include soil, seed, continuous cropping of the same crops, weeds, volunteer plants, improper use of biocides and growing environment. Navarrete et al. (2022) reported agroecological influence on the presence of both insect pests and diseases in Ecuador, and Kwambai et al. (2011) and Mwaniki et al. (2016) reported a reduction in BW incidence as altitude increased in Kenya. Bacterial wilt has been recorded in healthy-looking seed potatoes in Ethiopia at elevations above 3000 m asl (Sharma et al. 2018), possibly because of climate change. Late blight was critical during the long rains and BW during the short rains in all study sites, possibly because of favourable seasonal conditions for the diseases. This confirmed the findings of Muthoni et al. (2013) and Kwambai et al. (2011). Also, Muthoni et al. (2013) indicated that potato diseases remain one of the critical challenges in production, which suggests the need for proper management.

The recycling of seed potatoes, indiscriminate exchange of seed among farmers and possibly infected soils, coupled with the lack of proper management skills and active legislative measures to contain BW disease, remains a major threat in BW damage and spread particularly at the lower altitudes. Damtew et al. (2018) recommended implementing management strategies of LB and BW that, on one hand, are preventive of the disease spread, and, on the other hand, foster information sharing, learning and collective action among local actors in each system. Contrary to the common perception that new seed from another farmer or field was safe to use, Kassa (2017) found that sources of seed and seed recycling were major factors for high tuber yield loss and the main path of BW pathogen dissemination in Ethiopia. Recycling of seeds could be contributing to seed degeneration and increased diseases, especially with the small land sizes, which hinder crop rotation. It could be implied that the recycling of seeds contributed to seed degeneration, while lacking of crop rotation coupled with the recycling of seeds aggravated build-up and spread of insect pests and diseases. However, the attempt by some farmers to identify healthy crop sections for seed while growing in the field suggests a positive direction and actions that need technical support.

There was a rare mention of viruses among potato diseases during the surveys, which was suggestive that farmers were not aware of their importance or existence in potatoes. Thus, farmers could be spreading the disease unabated through the use of infected seeds. Also, farmers did not indicate the presence of potato cyst nematode (PCN), which suggested that they were not aware of it, or the problem did not exist in their areas. However, PCN was first detected in Kenya in 2015 (Mwangi et al. 2015; FAO 2017) and was reported to be rampant even in the potato growing areas studied (Mburu et al. 2020), which could be a contributor to some of the declining yield reported.

The use of fungicides by most (99.2%) respondents (Table 6) was attributed to the high incidences of LB, and the susceptibility of the varieties grown. Late blight costs growers both in fungicide control and yield losses in addition to health risks in handling the chemicals. There was an over-reliance on a small number of insecticides (e.g., Duduthrin; Lambda-cyhalothrin 17.5 g/l) and fungicide (e.g., Mistress; Cymoxanil 8% + Mancozeb 64%) or Ridomil (Metalaxyl-M) products which contain the same active ingredients possibly because of limited supply or lack of demand for varied products among farmers. Also, farmers lacked knowledge of the functioning of pesticides, skill in disease management and scouting for timely spraying of the appropriate pesticides. Reported pathogen resistance elsewhere to Metalaxyl (Deahl et al. 1995) and persistent use of single products by farmers may derail their efforts in late blight management. Pesticide resistance in pest organisms results from using the same pesticides repeatedly (Dang et al. 2017).

The weak positive correlation between fungicide uses and yield in the long and short rainy seasons, respectively, indicated that proper fungicides use could increase yields. This could be more gainful at high altitudes as indicated by the weak positive correlation between fungicide use and altitude since late blight could be more critical with a rise in altitude. Few farmers in Lelan used insecticides compared to Kaptama and Saboti, possibly because high altitudes did not favour insect pests as the lower altitudes. Although there was a weak positive correlation between insecticide uses and yield in both long and short rainy seasons, the results suggest that good practice could improve performance. On the other hand, a moderate negative correlation between insecticide uses and altitude confirmed the low use of insecticides at high altitude because of less insect pest problems. The weak positive correlation between insecticides or fungicides and yield could be attributed to improper biocides use. Thus, these results suggest the need for judicious use of pesticides supported by the use of disease or insect-pest-resistant varieties for better yields. There was room for increased yields through the proper use of available technologies with adherence to recommendations. However, farmers require appropriate knowledge on diseases and their management strategies to help them reduce the effects of important diseases such as BW, LB and viruses.

Crop Potation Practice

The high percentage of respondents (77.8%) practising crop rotation, suggests that farmers understood the need and value of crop rotation, although this was not clearly reflected in Lelan (Table 8). In Lelan, crop rotation was low because farmers have limited other crops of economic value as that of potato because of the low temperatures associated with the high altitude which affected their growth and performance. This was confirmed through observations during the household survey but the quality of crop rotations used by farmers was much below recommended practice. Recommended rotation cycle is to grow potatoes once every four seasons (Kaguongo et al. 2008: Wright et al. 2017), which may not be practical with small farm holdings. However, it could be innovatively modified with the use of suitable crop species with farmers trained to maintain clean fields free of tubers and volunteer plants. The big limitation among farmers could be on how best to implement an effective crop rotation within the limits of crops available and seasons. The challenge of continuous potato growing was expressed by one participant in Saboti during focus group discussions who quipped in *Kiswahili*, "*shamba imechoka kwa sababu aijapumsika"* (the land was tired, because it did not rest). Muthoni et al.

(2013) found that potatoes were grown without crop rotation where farm sizes were very small.

Crop rotation is an important practice in potato growing to maintain soil fertility and avoid build-up of soil-borne diseases (Kaguongo et al. 2008). Lemaga et al. (2001) found that planting different crops in two consecutive seasons reduced bacterial wilt compared to planting the same crop, and that rotation of potato with maize, beans, onions, millet, peas and sweet potato gave significantly higher yields than potato monoculture. Also, Wright et al. (2017) reported a reduction in diseases and increased yields through crop rotation. By inclusion of *Crotolaria falcata* as a component of crop rotation practice and fallowing, Kakuhenzire et al. (2013) reduced bacterial wilt by > 85%. Many of the crop rotation practices were not based on good agricultural practice and the tendency towards very poor crop rotation practice and few alternative crops recorded in Lelan suggests the need to introduce more adapted crops for diversification and crop rotation. The lack of systematic crop rotation sequences and intervals indicated that farmers lacked the necessary knowledge. Most producers practice short crop rotations and others grow potatoes with no crop rotation leading to build-up of pests and diseases in the soil (Lung'aho and Schulte-Geldermann 2016), and this is worsened by farmers leaving infected or uneconomical tubers scattered on the ground. In Lelan, higher potato yields could have been attributed to improved soil conditions because some farmers planted potato in virgin fields and/or crop rotation involved fields left as fallow. In Saboti, some farmers grew potatoes in government forests under the *Shamba* system (planting of crops in cleared forests as planted seedlings are maintained until the crops can no longer be sustained).

The strong ($R=-0.696$) negative correlation between crop rotation and altitude confirms that more farmers in Lelan did not practise crop rotation compared to those in Saboti and Kaptama (Table 5). Generally, the negative correlation between crop rotation and most farmer practices and also yield suggests that crop rotation was not beneficial in potato production. However, this could be attributed to inconsistencies or poor crop rotation practices among farmers. Although most farmers did not practise crop rotation in Lelan, higher yields were realized compared to Saboti and Kaptama (Fig. 7). Despite the negative correlation between crop rotation and most parameters measured, the moderate positive correlations with overall farmer agronomic practice suggest that crop rotation was necessary as were other crop management practices.

Treatment of Volunteer Plants

The common practice of retention of volunteer plants by most respondents showed that potato growers lacked adequate knowledge of good agricultural practice for high land productivity. The high percentage of retention of volunteer plants in Lelan compared to Kaptama and Saboti was attributed to the high survivability of seed tubers in the soil and the importance placed on the potato as the economic and food security mainstay. The harvesting of the volunteer potatoes for food or cash brings about compromises in crop management and suggested that farmers lack knowledge on the negative effects of volunteer plants. Kwambai et al. (2011) in a previous study reported retention of volunteer potato plants among farmers (77.5%) in the same areas. Volunteer plants interfere with rotation programmes and cause significant weed problems since large numbers of potato tubers remain in the field after harvest (Allemann 2016).

Volunteer plants act as weeds and hosts for insect pests (aphids, potato tuber moth), nematodes and soil-borne (e.g., bacterial wilt) and other (e.g., viruses) diseases from one season to the other (Nganga and Schideller 1982). Retention of volunteer plants has a negative effect on productivity since it encourages disease build-up and spread (Allemann 2016). However, the success of volunteer plants as claimed by farmers and the value attached to it suggest a need for timely and early planting through the adoption of staggered planting with the right varieties for example early maturity types as an approach to embracing better practices to achieving an early crop for food security and cash. The weak positive correlation between the treatment of volunteer plants with yield and altitude showed that the removal of volunteers was advantageous in potato farming.

The variation among the study sites in potato yields supports the hypothesis that "potato farming and management practices does influence potato performance (depending on production environment)". Overall, all sites had poor agronomic practice with Lelan providing higher yields than Kaptama and Saboti possibly because of a more favourable environment, slightly better use of fertilizer and presumably better seed. Farmers' practices were far below the national recommendations, which suggests a need to determine the farmer-based costs and their relationship with the potential productivity of the study areas. The weak and moderate positive correlations between input use and yield could be attributed to the insufficient quantities applied and possibly poor timing of application. Generally, the results indicated that overall farmer agronomic practice in the use of inputs positively correlated with yield during both the long and short rainy season, which implies that appropriate use of the various inputs could considerably increase yields possibly as a result of synergistic effects among inputs.

Ridging and Weeding Management

Farmers ridged potatoes during weeding as opposed to prior to planting because it was laborious work. Ridging contributes to increased yields, prevention of tuber greening and pest damage (Sakadzo et al. 2019). Manual weeding was a common practice, labour intensive and costly. Its efficiency varies depending on weather conditions, skill and integrity of the person(s) weeding, tools used and timing of the weeding operation. Weeds were more problematic and costly in Lelan compared to Saboti and Kaptama, possibly due to the inefficient manual weeding, slow crop growth caused by lower temperatures as influenced by altitude. The slow crop growth coupled with commonly low-quality seed in many cases delayed ground cover, which suggests that weeding must be approached differently at high altitudes from lower altitudes, where both crop and weed growth are faster and where weeds are desiccated easily after weeding. The use of herbicides has been successful in other countries (Janaki et al. 2017; Abdalla et al. 2021).

Timely operations on ridging or earthing up and weeding are crucial because a delay in manual weeding may result in the damage of tubers forming or bulking, which eventually leads to reduced yield from the weeds and damaged tubers. Also, injuries on tubers provide avenues for disease infections, and weeds may serve as hosts to insect pests and diseases (Nganga and Schideller 1982), which emphasizes the importance of timely weeding. Although herbicides were not being used in potato at all the study sites, farmers during focus group discussions expressed willingness to use them, particularly in Lelan.

Harvesting Management and Marketing

The common use of a hand hoe in harvesting was attributed to the lack of mechanized machinery. Generally, harvesting was not done based on recommended practices but rather on the needs of the farmer (i.e., cash) or the buyer (i.e., produce). The harvesting of potatoes early and without dehaulming indicated that farmers lacked sufficient knowledge on the importance of optimum harvesting time and the post-harvest consequences of search practices at both household level and along the marketing value chain. The urgent need for household cash, fluctuation in ware potato supply, and the compromises of quality by buyers contributed a lot to early harvesting. Harvesting without hardening by dehaulming predisposes produce to post-harvest damages and losses. Also, harvesting potatoes before full maturity compromises the achievement of maximum yield and quality produce. Premature harvesting of potatoes makes post-harvest handling of potatoes the most important driver of quality, prices, produce losses and producer returns (Fintrac 2015). Harvesting before full maturity is profitable only when a premium price is paid for immature potatoes that are sold immediately (Schweers et al. n.d.), a practice rarely done in Kenya. The low percentage of respondents (4.9%) who dehaulmed their potato crop only for seed suggested that very few farmers planned for their seed in advance for the next season's crop. The practice of selecting seeds from harvests or leftovers after harvest instead of having separate seed crops points to low seed quality for the subsequent planting.

Sprouting of tubers at harvest as we observed with Shangi in Lelan indicated the problem farmers face when they retain the variety in the field for extended periods (Fig. 14A). Although the farmers indicated that Shangi could still be sold after the removal of the sprouts, the quality of such tubers would be compromised immensely. The tendency for Lelan farmers to grow only Shangi in all seasons was because of its demand and the influence of the brokers supplying the markets, which was different from Saboti and Kaptama with more marketing agents and diversified market destinations with somehow different preferences. Although Shangi was predominant in Lelan, the purchase of other varieties such as Arka and Kabale in Kaptama and Saboti by the brokers indicated that the brokers in Lelan were more selective and hence strongly influenced variety choice and not necessarily the market alone since the same produce was taken to almost similar distant major markets including Uganda as for Saboti and Kaptama.

Access to Agricultural Information

The heavy reliance on family members and neighbour farmers for the exchange of information indicated that access to extension information required interventions from government agencies and other relevant stakeholders. Some of these might not have been listed as possible channels in this study such as Research organizations, Agricultural Sector Development Support Programme (ASDSP), Technoserve and Syngenta Foundation. The farmer-to-farmer information exchange is always readily available but it will not enhance production to fully meet farmer needs and national objectives of transforming potatoes from subsistence to a viable commercial enterprise (MoAL&F 2016). Agricultural knowledge is passed down generationally and within communities but limits access to improved technologies (Feed the Future n.d.).

Agricultural information is vital for any progressive improvement in farming, particularly in potato production, which requires the right knowledge and skills from seed to post-harvest handling of both ware and seed potatoes. The need for improvement of farmers' knowledge in Kenya has been emphasized (Gildemacher et al. 2009; Janssens et al. 2013; Soethout and Castelein 2021; Sharma and Atieno 2021). Provision of appropriate information to potato farmers on issues of seed, fertilizer, insect pests and diseases, crop rotation, intercropping, volunteer plants and storage management among other practices could bring about significant improvement in potato production, particularly among smallholder growers. Also, de Vries et al. (2017), working in Sudan, indicated that farmers needed agricultural knowledge and skills in the use and effects of agricultural inputs on their crops, the environment and health. Smallholder farmers need proper potato production information, disseminated to them, so that potatoes are produced optimally (Janssens et al. 2013).

The data and information obtained about the farming practices and challenges affecting productivity add new knowledge about the otherwise less reported potato growing areas, where optimal management practices and many new technologies have not been tried, yet have potato growing potential. Inadequate introduction of technologies and lack of exposure of farmers to good agricultural practices and to improved socio-economic conditions continue to hinder progress in the sub-sector. Farmers will invest in and implement sustainable technologies and farm practices if they expect the investment will be profitable, supported by the right education, information, motivation, and government policy (OECD 2001).

Conclusions and Recommendations

The study revealed that farmers were not fully benefiting from the existing potato production potential mainly due to lack of access to quality seed, disease damage, poor marketing, inadequate technical knowledge and lack of investment capital, which were key issues for attention. Also, farmers' practices were far below the national recommendations. The big question was on how best to implement effective crop management practices such as crop rotation, seed production and seed use within the limits of small farm sizes, crops available, seasons and farmers' socio-economic status. Lelan with relatively larger land sizes and a cooler environment could provide ideal conditions for strategic seed multiplication under defined crop rotation and seed renovation system(s), supported by the introduction of adaptable crops for crop rotation.

The use of small quantities of fertilizers was one of the key factors contributing to the low potato yields in addition to poor seed quality. Seed quality management goes beyond following technical knowledge and requires collective action. Also, result demonstrations on the use of the certified seed, fertilizers, pesticides and quantities applied are necessary to enhance farmers' understanding and appreciation of the benefits of optimum input use, supported by improved access to quality seed of the right improved varieties, appropriate fertilizers at affordable prices and access to agricultural information. As such the region and country can feed its increasing population despite the small land sizes.

It was evident that potato growing for sale was the major driving factor in the cultivation of potatoes irrespective of the land size, site or status of the farmer, while food security was secondary. To ensure a consistent supply of potatoes, proper utilization of existing growing environments and seasons with enhanced irrigation are important interventions. Also, the use of viable extension approaches to provide farmers with access to agricultural information as opposed to the current situation where farmers mainly relied on their counterpart farmers or family members needs to be emphasized.

Modification of the agronomic practices in line with the existing farming systems could improve the adoption of technologies and hence increase productivity. In order to achieve higher productivity, it was imperative to train farmers in potato crop management for both ware and seed, and possibly develop varieties with low input requirements. The key research gaps identified in this study particularly in the use of inputs and diagnosis into socio-economic aspects influencing farmer practices and technology adoption may have future solutions for a growing potato industry. It is anticipated that knowledge of farmers will drive demand for inputs, which in turn will drive supply if credit is available supported by good produce prices. Such realization will increase input use which will pyramid into an increase in yields and hence income. Generally, the results indicated that overall agronomic farmers' practice in the use of inputs had a positive correlation with other input uses and yield during both the long and short rainy season, which implied that improved use of the various inputs could considerably increase yields.

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Data Availability All data are available in the Supplementary material.

Declarations

Confidentiality of Information The focus group discussion participants and household survey respondents were informed that taking part in the study was voluntary and the information collected would be kept with confidence and used only for the purpose of the research conducted.

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

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