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Potato Diseases Surveillance in Kenya

Project Report

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KNOWLEDGE FOR LIFE

Implementing Institutions

CAB International (CABI)

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Project Partners

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Acronyms and Abbreviations

ADC	Agricultural Development Corporation
ANI	average nucleotide identity
approx.	Approximately
ASTGS	Agricultural Sector Transformation and Growth Strategy
bp	base pair
BRR	Bacterial Ring Rot
CABI	CAB International
CCO	County Crops Officer
CDA	County Director of Agriculture
CFU	Colony-forming units
CHCO	County Horticultural Crops Officer
CIP	International Potato Center
CO	Chief Officer
COPE	Centre of Phytosanitary Excellence
CSV	Comma Separated Values
CTAB	Cetyl Trimethyl Ammonium Bromide
CVP	Crystal Violet Pectate
DCDA	Deputy County Director of Agriculture
DDH	DNA-DNA hybridization
DL-CVP	Double-layer Crystal Violet Pectate (CVP)
DMSO	Dimethyl sulfoxide
DNA	Deoxyribonucleic acid
dNTP	Deoxyribonucleotide triphosphate
DO	Data Officer
DoA	Department of Agriculture
D-PEM	Double Strength Pectate Enrichment Medium
EDTA	Ethylenediaminetetraacetic acid
FAP	Field Assessment Personnel
FFSs	Farmer Field Schools
g	Gram

GDP	Gross Domestic Product
h	Hour
ha	Hectares
IPPC	International Plant Protection Convention
IPTG	Isopropyl β-D-1-thiogalactopyranoside
ISC	Invasive Species Compendium
ISPM	International Standard for Phytosanitary Measures
KALRO	Kenya Agricultural and Livestock Research Organization
KEPHIS	Kenya Plant Health Inspectorate Services
KES	Kenya Shillings
LAMP	Loop-Mediated Isothermal Amplification
LB	Luria Broth
LBA	Luria Bertani Agar
Ltd	Limited
masl	meters above sea level
MECs	Mass Extension Campaigns
mg	Milligram
min	Minute
mL	Millilitre
MLSA	multilocus sequence analysis
mM	Mllimolar
MoALF	Ministry of Agriculture Livestock and Fisheries
Mt.	Mountain
NA	Nutrient Agar
NARL	National Agricultural Research Laboratories
NB	Nutrient Broth
NBY	Yeast extract Glucose Mineral Medium
NCPPB	National Collection of Plant Pathogenic Bacteria
NGM	Nutrient Glycerol Manganese
NGOs	Non-governmental Organisation
No.	Number
NPCK	National Potato Council of Kenya
ODK	Open Data Kit
PCN	Potato cyst nematode
PCR	Polymerase chain reaction
PFAs	Pest Free Areas
PLRV	Potato Leaf Roll Virus
PMDG	Pest Management Decision Guides
PRA	Pest Risk Analysis

PTN	Potato tuber nematode
PVA	Potato Virus A
PVM	Potato Virus M
PVP	Polyvinylpyrrolidone
PVS	Potato Virus S
PVX	Potato Virus X
PVY	Potato Virus Y
rpm	Revolutions per minute
SCADO	Sub-county Agricultural Development Officer
SCAO	Sub-county Agricultural Officer
SCAPMO	Sub-county Agricultural Production and Marketing Officer
SCCDO	Sub-county Crops Development Officer
SCCO	Sub-county Crops Officer
SDS	Sodium Dodecyl Sulfate
sec	Seconds
SL-CVP	Single-layer CVP
SMS	Short Message Service
S-PEM	Single Strength Pectate Enrichment Medium
SRE	Soft Rot *Enterobacteriaceae*
SRP	Soft Rot *Pectobacteriaceae*
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
t	Tonne
TAE	Tris-Acetate-EDTA
Taq	*Thermus aquaticus*
TE	Tris-EDTA
Tris	Tris(hydroxymethyl)aminomethane
UoN	University of Nairobi
USD	United States Dollars
V	Volts
VC	Value Chain
WAO	Ward Agricultural Officer
WCDI	Wageningen Centre for Development Innovation
YGM	Yeast extract Glucose Mineral Medium

Executive Summary

The agriculture sector contributes 33% of the Gross Domestic Product (GDP) to Kenya's economy and adds another 27% through linkages to other sectors such as manufacturing, distribution and services. It is the main source of direct income and livelihoods for about 70% and 40% of the rural and Kenya's total population respectively. The Agricultural Sector Transformation and Growth Strategy (ASTGS) prioritized 13 Value Chain (VC) including potato with potential to raise smallholder farmer incomes and offer dietary diversity. This is in line with the "Big Four" agenda which includes food security in addition to affordable housing, manufacturing and affordable healthcare for all. Potato (*Solanum tuberosum* L.), one of the prioritized VCs, is only second to maize in importance, contributing more than USD 300 million annually to the economy and employing about 3.3 million people directly and indirectly as; producers (growers), brokers, market agents, transporters, processors, vendors, retailers and exporters. Potato farmers are estimated at 800,000 and spread across a number of counties which include, Bomet, Bungoma, Elgeyo Marakwet, Kericho, Kiambu, Kirinyaga, Meru, Muranga, Nakuru, Narok, Nyandarua, Nyeri, Trans Nzoia, Uasin Gishu and West Pokot.

Kenya is the 4^{th} leading producer of potato in Africa after Egypt, Algeria and South Africa producing potato on an acreage of 217,315 ha which is only second to Nigeria according to 2018 figures from FAOSTAT. Total production in the same period resulted in a total tonnage of 1,870,375 t giving an average yield of 8.6 t/ha. This yield is far below the Africa and global averages and most countries in Africa including East Africa except Uganda. Kenya's potato yield has progressively decreased from 21.2 t/ha in 2008 to 8.6 t/ha in 2018. This is attributed to a number of factors which include but are not limited to low availability of certified seed potato, low usage of certified seed potato, limited or no crop rotation, declining soil fertility, low usage of agro-inputs, inability to take advantage of irrigation to enable year-round production but as a major factor, high pest incidence. A number of pests especially *Alternaria solani*, *Phytophthora infestans*, *Ralstonia solanacearum* and viruses (especially potato viruses X, Y and potato leaf roll virus) have been widely reported in Kenya. Other pests affecting potato production include *Clavibacter sepedonicus*, the cause of bacterial ring rot; *Dickeya* species, the cause of soft rots; and *Pectobacterium* species, the cause of blackleg and soft rots. Species in the genus *Dickeya* and *Pectobacterium* colectively belong to the Soft rot *Pectobacteriaceae* (SRP). *Pectobacterium* species identified in Kenya in previous studies include *P. brasiliense*, *P. carotovorum*, and *P. parmentieri*.

C. sepedonicus, species in the genus *Dickeya* and some in the genus *Pectobacterium* are listed as quarantine pests in Kenya. A horizon scanning assessment conducted in 2018 by CABI with other stakeholders in the plant health system including KEPHIS highlighted *C. sepedonicus* and some Soft rot *Pectobacteriaceae* (*D. dadantii*, *D. dianthicola*, *D. solani*, *D. zeae*, *P. atrosepticum*, and *P. parmentieri*) as high risk to Kenya's agricultural sector. A surveillance exercise was conducted to determine the presence of bacteria that incite blackleg and soft rots (*Dickeya* sp. and *Pectobacterium*. sp.) and bacterial ring rot (*C. sepedonicus*). The exercise was conducted in the six major potato producing counties of Kenya selected through a consultative process by stakeholders. The counties included; Elgeyo Marakwet, Meru, Nakuru, Narok, Nyandarua and Trans Nzoia. A fact-finding mission that brought together key county officials was conducted in each of the counties. The objective of this mission were five-fold, i) explain the rationale of the potato disease surveillance exercise; ii) share the surveillance protocol with the county officials; iii) ascertain facts about potato production and associated pests (especially the target pests) in the county; iv) identify areas within the county (potato growing areas) to undertake the surveillance work; and v) agree on the timelines and involvement of county personnel in the surveillance work. Apart from collecting samples from which the pathogens were isolated, a structured questionnaire was also administered to all the farmers from whose fields the samples were collected. Prior to the surveillance exercise, all Field Assessment Personnel (FAP) under went training at the National Agricultural Research Laboratories (NARL), Kabete, Nairobi, Kenya. The objective was to ensure that the whole team understood the protocol, the symptoms and signs of the target pathogens, the procedure for sample collection, and how the integrity of the samples was supposed to be protected.

The surveillance exercise was conducted during the second (short rains) season of 2019 commencing on 1^{st} December and ending on 20^{th} December 2019. The FAP interviewed and collected samples from 1,002 farms across the six counties. All samples were delivered to KEPHIS within 24 hours of collection. Of the 1,002 farmers, female accounted for 42% (421) and male, 58% (581). The majority came from Nyandarua county (317, 32%), followed by Nakuru (268, 27%), Meru (122, 12%), Trans Nzoia (110, 11%), Narok (94, 9%) and lastly Elgeyo Marakwet (91, 9%). In addition to disaggregation by gender, the farmers were also disaggregated by age. Five age categories were considered which included $<$30 years, 31-35, 36-45, 46-55 and $>$55 years. The least category interviewed was the $<$30 year (85, 8%); followed by 31-35 year (127, 14.5%); then 36-45 years (248, 24.8%); $>$55 years (254, 25.3%) and lastly, the 46-55 year (288, 28.7 %). The majority of farmers (830, 83%) selected potato as the first-choice crop followed by maize (112, 11%) in the distant second. However, maize was preferred by most farmers (437, 43.6%) as the second-choice crop after potato. Potato also accounted for the biggest acreage followed by maize but came third after maize and cabbage when selected as second choice. A similar trend was observed across counties.

In total, 28 varieties were grown across all counties with 16 selected as their first-choice. Shangi was selected by the majority (899, 89.7%) followed in the distant second by Dutch Robijn (33, 3.3%). Four other varieties were selected at least by more than 10

farmers which included Asante (16, 1.6%), Tigoni (11, 1.1%), Kabale (10, 1.0%) and Sherekea (10, 1.0%). The majority of farmers obtained their potato planting materials from informal sources. A proportion of 34.1% (342) obtained from fellow farmers, 32.1% (322) used own-saved materials and 19.9% (199) sourced from both categories resulting in totals of 521 (51.2%) and 541 (54%) who sourced from fellow farmers and used own-saved planting materials respectively. A small proportion of 5.1% (51) sourced potato planting materials from the market. Only 17.2% (172) of the farmers sourced seed from seed producers. Other sources indicated by 1.4% (14) of the farmers included the county governments and and Non-governmental Organisation (NGOs). The majority of farmers claimed to have used appropriate agronomic practices that improve crop productivity such as recommended spacing (911, 90.9%), fertilizer application (987, 98.5%), scouting for pests (896, 89.4%), crop rotation (753, 75.1%), pest management (987, 97.1%) and weeding (973, 97.1%). Only 9.3% (94) irrigated their crops and 33.1% (332) used improved seed. Although 98.2% (984) did not mulch their crop, it is not an essential practice in potato production. A similar trend was observed across counties.

Crop rotation was used across counties by 75% (753) of the farmers with maize (546, 54.5%) being the most rotated crop with potato followed by cabbage (226, 22.6%). A similar trend was observed across all counties. Maize was also the second-choice crop after potato with cabbage coming in a distant third probably explaining the choice of these crops in rotations. Although it was a small fraction (5, 0.5%), some farmers rotated potato with tomato for which they share the same pests. This is not a good agronomic practice and needs to be addressed through awareness and farmer training. Irrigation was only reported by 8.9% of the total (1,002) number of the farmers. Sprinkler irrigation was the most used and mostly in Meru (66 of the 89; 74.1%) followed by Nyandarua (20 of 89; 22.5%) confirming reports of low usage and mostly around the Mt. Kenya region. The majority (more than 50%) of farmers claimed to deploy various agronomic practices to manage pests such as *A. solani*, *P. infestans*, *R. solanacearum*, white flies, cutworms, aphids. SRP-associated diseases especially blackleg were mentioned by approximately 2% of the farmers (20 of 1,002) while bacterial ring rot was not mentioned at all. The majority (964, 96.2%) of farmers used their own experience for crop management however, 56.5% (566) obtained information from friends, 56.5% (566) from radio, 54.8% (548) from government extension while demonstration and agro-dealer were selected by more than a third of the farmers.

Seven farmers (equivalent to 7 in 1,000) indicated to have observed bacterial ring rot while 17% (170) indicated to have observed presence of SRP-associated diseases (blackleg in plants and soft rots in tubers). Nakuru and Nyandarua recorded the highest and comparable observations of SRP-associated diseases followed by Elgeyo Marakwet and Narok whose observation were also comparable but significantly less with Trans Nzoia recording the least. It should also be noted that Nyandarua and Nakuru had the highest number of samples collected from the farmers. Bacterial ring rot perceived observations could have been confused with other plant health problems however, the low perceived observations of blackleg and soft rots does not indicate absence of the disease but probably a confusion of symptoms, lack of knowledge of the

disease or latent infections. The action taken by the majority of farmers to managed SRP-associated diseases was to do “doing nothing” (56%, 96 of 170) followed by uprooting (42%, 73 of 170) especially for blackleg. Interestingly, 15.3% (26 of 170) farmers used chemicals to manage blackleg while only 5 (approx. 3%), reported the cases to extension officers. Use of chemicals to manage diseases caused by bacteria is not a cost-effective and effective management strategy. The preferred choice of information dissemination selected by the majority of farmers was mobile messaging followed by extension. The two choices in the same order were echoed across the six counties.

Selective or targeted sampling (mentioned in ISPM 6 and described in ISPM 31) was employed to obtain samples. This is because the surveillance exercise focused on a host and pathogenic organisms that were deliberately targeted with the objective of detecting presence. This surveillance exercise was not aimed at providing information about levels of infestation or distribution of the pathogen. The farmers from whom the samples were obtained, were selectively identified by the WAO and CDA. The selection was based on two criteria, the farm should have had a long history of potato production (at least three previous seasons) and had at least observed suspected cases of the target pathogens. The two criteria gave a higher chance of obtaining the target pathogens because of the perceived disease presence. Samples were collected from plants showing symptoms associated with the target pathogens. In addition, soil was collected because blackleg and soft rot bacteria survive in soil for between 1 week to 6 months, depending on environmental conditions such as soil temperature, moisture and pH although survival can be longer if there are volunteer plants. In case symptomatic plants were not observable, then simple random sampling (also described in ISPM 31) was employed to give equal probability in selecting samples. Randomness was achieved either by walking and examining hosts in a large zigzag pattern across the field. In this case, more than one plant sample was collected per farmer field visited. To avoid transfer of pests from farmer to farmer and plant to plant, disposable gloves were used and changed between farmers and plants in the field. In addition, the FAP also sterilized their shoes with 5% Sodium hypochlorite in between farmers’ fields to avoid transmission of soil-borne pests. All samples were packaged in Khaki paper bags and given unique codes (identifiers) derived from the county, sub-county and ward names and initials of farmers’ names and sent immediately by courier to Bacteriology unit of the plant health laboratory at KEPHIS headquarters with in 24 hour of collection. The unique identifiers were also linked to the detailed information collected about the farmer through a structured questionnaire administered using tablets using the Open Data Kit (ODK) platform.

All samples were kept at 4^{o}C in the cold room on arrival at KEPHIS Laboratories and processed within 24 h. Using sterlised implements, whole plant samples were separated into pieces of leaves, stems, roots and tubers and kept at -20^{o}C until needed for isolation. Soil samples were measured in approx. 40 g portions and also kept at -20^{o}C. All the samples obtained were asymptomatic for bacterial ring rot while the majority were asymptomatic for blackleg and soft rots. *C. sepedonicus*, and the genera *Dickeya* and *Pectobacterium* were isolated following established

procedures. An enrichment step was included in the isolation procedure for *Dickeya* and *Pectobacterium* genera to enrich the bacteria to detection levels since most samples were asymptomatic. The total number of samples from which the bacteria were isolated were 2,834 samples comprising of 1,334 stem and 696 tuber and 804 soil samples (only for blackleg and soft rots). Following isolations, molecular diagnostic tools especially end point PCR using published primer sequences for respective target pathogenic species was conducted. *C. sepedonicus* was not identified in any of the samples obtained correlating with the few observations by the farmers which was attributed probably to confusion of symptoms with other plant health problems.

The genera *Dickeya* and *Pectobacterium* were identified in 291 samples of which 63% (183) were stems, 32% (92), soil and 5% (16) were tubers. The varieties from which they were isolated comprised of Shangi (177, 89%), Dutch Robijn (18, 9%), Asante (2, 1%), Destiny (1, 1%) and Kabale (1, 1%). The majority of isolations were from samples obtained from Nyandarua, 65% (190 of 291) followed by Narok (16.5%, 48 of 291) then Nakuru (7.9%, 23 of 291), Meru (4.8%, 14 of 29), Elgeyo Marakwet (3.4%, 10 of 291), and Trans Nzoia (2%, 6 of 291). *Dickeya* spp. was identified in two samples (tubers) obtained from two farms, one in Elgeyo Marakwet and the other in Narok. The sample from Narok also tested positive for a species of *Pectobacterium*. Additional surveillance in Elgeyo Marakwet and Narok through contact tracing confirmed the genus *Dickeya* on 5 of the 12 farms of which one tested positive for *D. solani*. Also surveillance by a team from KALRO confirmed presence of *D. solani* and *D. dianthicola* in Taita Taveta. The genus *Pectobacterium* was identified in 290 samples which is equivalent to one in every ten samples. Using species-specific primers, *P. atrosepticum* was confirmed in 29 samples, 9 of which were soil and 20, stems distributed across all the six counties. *P. brasiliense* was identified in 46 samples comprising of 16 soil samples, 28 stem sample and 2 tuber samples. *P. carotovorum* was identified in 39 samples comprising of 27 stem samples, 11 soil samples, and 1 tuber samples. *P. parmentieri* was confirmed in 39 samples which comprised 34 stem samples, 13 soil samples, and 4 tuber samples. As indicated, many other samples tested positive for the genus *Pectobacterium*. In addition to identifying two species from the same sample as indicated above, multiple species were also identified in the same field as well as same sample. In some fields, same *Pectobacterium* subspecies were identified in the soil and the plant (stem or tuber). This could probably be a case of seed- and soil-borne transfer which underscores the role of using potato planting materials from the informal sector in spreading blackleg and soft rots and probably other pests such as reported with *R. solanacearum*, nematodes and viruses. The identification of the genus *Pectobacterium* in soil as well as the genera *Dickeya* and *Pectobacterium* from a majority asymptomatic samples demonstrates that this is a plant health problem that has to be addressed.

Although low yields have been observed in Kenya (average 8.6t/ha), these low yields cannot only be attributed to management practices used by potato farmers. Some of these practices were aimed at managing some pest which did not include *C. sepedonicus* and the genera *Dickeya* and *Pectobacterium*. This demonstrated a poor understanding of these problems especially blackleg and soft rots. The low yields could partly be attributed to the poor quality of potato planting materials where there

is over-dependence on the informal sector. This has resulted in planting materials infested with pests resulting in soil contaminating with soil-borne pests. If available, pest free areas can be delineated especially for production of potato seed. There is need to address the issue of over-dependence on seed from the informal sector probably through supporting interventions that increase availability of certified seed or clean seed where farmers use home-saved seed. Some of these interventions include positive seed selection and seed plot technique both of which improve the quality of farmer-saved seed. Although *C. sepedonicus* was not identified in the samples tested, it is essential to conduct routine surveillance to update its status of this pest in the country. Most farmers were not conversant with blackleg and soft rots which was compounded with a lack of knowledge on actionable management options. It is important that fit-for-purpose information and communication materials are developed and used in raising awareness amongst various stakeholders especially farmers, extension and agro-input suppliers. Evaluation of potato varieties against SRP-associated diseases will improve extension advisory. The confirmation of presence of Soft rot *Pectobacteriaceae* necessities a review of the quarantine status of some of the *Pectobacterium* species and the genus *Dickeya*. Pest-initiated pests risk analysis (PRA) need to conducted for *P. atrosepticum*, *D. solani*, and *D. dianticola* to assist in deciding the most appropriate actions that will reduce the risk of damage these pests may have on plants and plant products.

1

Introduction

1.1 Background

Three in four Kenyans live in rural areas and derive their livelihood from production, processing, and marketing of crop, livestock, fish, and forest products (1). Agriculture is central to Kenya's economy contributing 33% of the GDP, adding another 27% through linkages to manufacturing, distribution and services. This sector is the main source of income and livelihoods for about 70 and 40% of the rural and Kenya's total population respectively. The ASTGS prioritized 13 VC with potential to raise smallholder farmer incomes and offer dietary diversity (1). Potato was included amongst the 13 VCs

Potato (*Solanum tuberosum* L.) is the second most important crop in Kenya after maize, contributing approx. USD 300-400 million annually to the economy. The potato VC employs about 3.3 million people directly and indirectly as producers (growers), brokers, market agents, transporters, processors, vendors, retailers and exporters. Growers who are predominantly smallholders are estimated at 800,000 and grow the crop on average land areas of approx. 0.47 ha. Potato is also key to food and nutritional security and has been demonstrated to be rich in vitamins, minerals, proteins, antioxidants, essential amino acids as well as carbohydrates (2). The prospects for growth of the market for fresh potato makes potato a good alternative for addressing food prices which opens up opportunities for rural development in Kenya (3).

Globally, the crop is grown in a wide range of altitudes, latitudes and climatic conditions both in the tropics and sub-tropics during cool and dry seasons (although under irrigation) (4). In Kenya, it is predominantly grown in high altitude areas between 1,500 and 3,000 masl and annual rainfall of between 1,050 and 1,900 mm. Traditionally, the crop is produced in the counties of Bomet, Bungoma, Elgeyo Marakwet, Kericho, Kiambu, Kirinyaga, Meru, Muranga, Nakuru, Narok, Nyandarua, Nyeri, Trans Nzoia, Uasin Gishu and West Pokot however, increased demand has shifted production to non-tranditional counties such of Embu, Kajiado, Kwale, Machakos, Makueni, Samburu and Tharaka Nithi with counties such as Baringo, Kisii, Laikipia, Nandi and Nyamira considered potential growing areas (Figure: 1.1) (5).

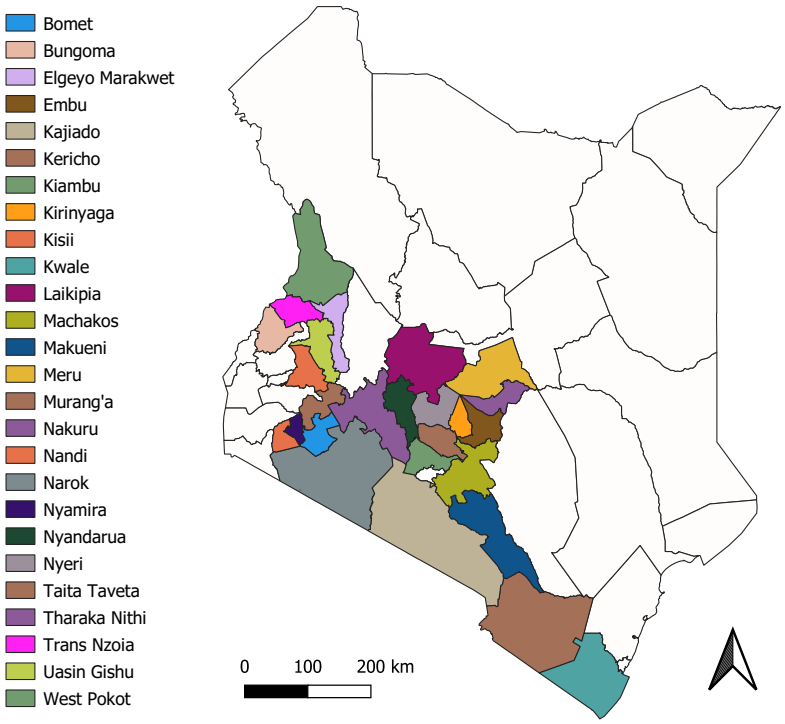


Figure 1.1: Traditional, emerging and minor potato production of Kenya; This image has been reproduced from the National Potato Strategy of Kenya 2016-2020

1.2 Production

Potato is majorly produced in two rainy seasons, the first (April - August) and second (September - January) with the length of the season dependent on the region (6). Limited off-season production has been reported at high altitudes especially 2,000 masl and on slopes of Mt. Elgon and Kenya which receive intermittent rainfall. Irrigation is limited and reported only around the slopes of Mt. Kenya where farmers use small sprinklers connected to up-slope streams operated using the force of gravity. This year-round production makes Kenya the 4^{th} and 32^{nd} producer in Africa and the world respectively. In 2018, 1,870,375 t of potato were produced from 217,315 ha giving an average yield of 8.6 t/ha (FOASTAT, 2018[1]). Kenya's potato yield was lower than that of Egypt, 27.7 t/ha (4,896,476 t from 176,670 ha); Algeria, 31.1 t/ha (4,653,322 t from 149,665 ha) and South Africa, 36.1 t/ha (2,467,724 t from 68,277 ha) (Figure 1.2) yet it was produced from far greater hectarage. It was also lower than the Africa (14 t/ha) and global (20 t/ha) averages but only (Figure 1.3). In East Africa, Kenya's yield was only better than Uganda as demonstrated in Figure 1.3. However, the interesting observation was a consistent decline in yield since 2008.

[1] http://www.fao.org/faostat

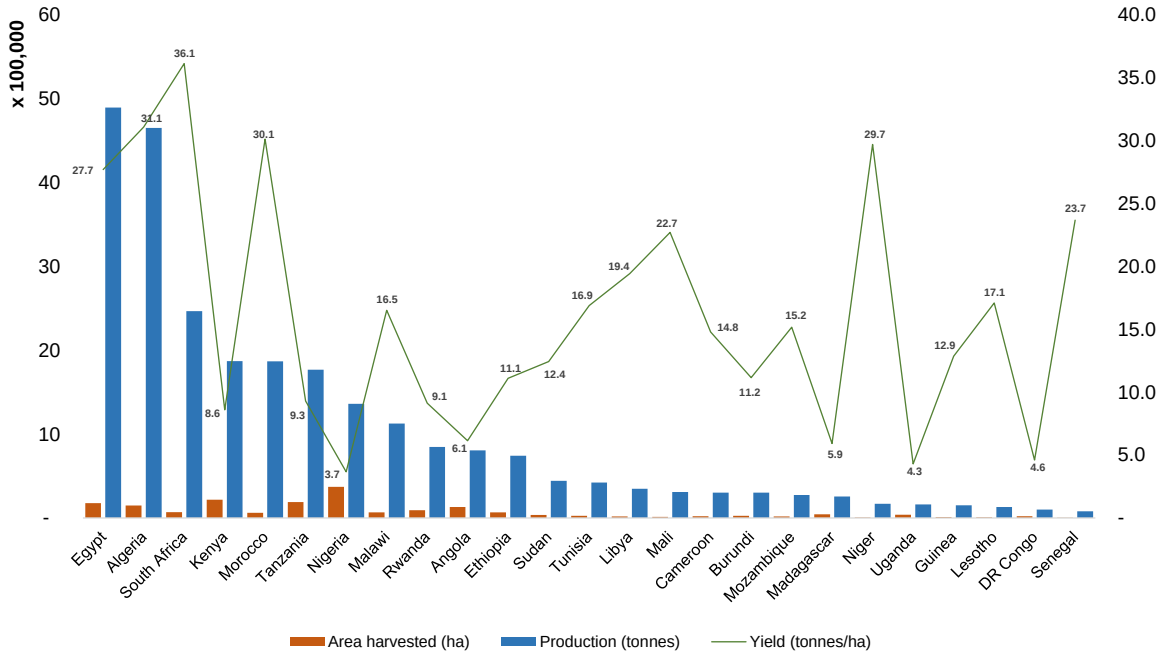


Figure 1.2: Area harvested, total production and yield of potato for the top 25 countries in Africa in 2018. Source: FAOSTAT, 2018 (http://www.fao.org/faostat)

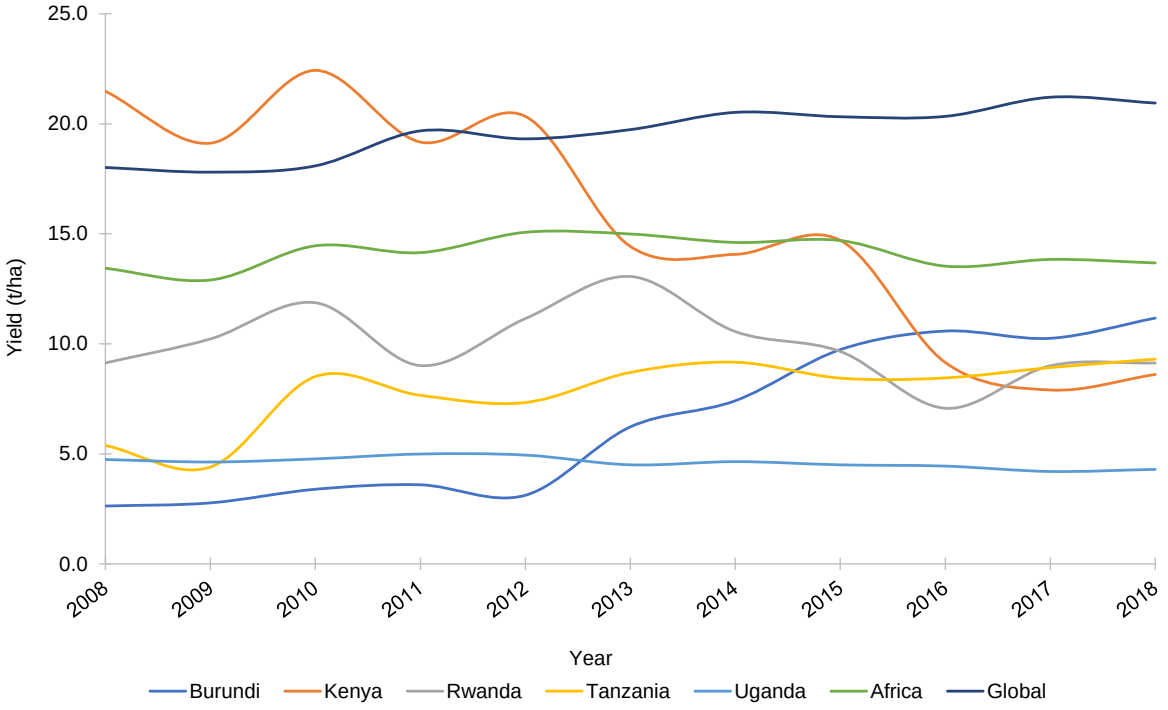


Figure 1.3: Africa, Global, and East African average potato yields from 2008 - 2018. Source: FAOSTAT, 2008 - 2018 (http://www.fao.org/faostat)

1.3 Production Challenges

The observed reduction in yield described in Section 1.2 is attributed to a number of factors the causes of which are presented in Figure 1.4 and briefly expanded below.

1.3.1 Low Availability of Certified Seed

Shortage of certified seed results in farmers utilizing planting materials from the informal sector (such as farm-saved, from local market or neighbours) which accelerates spread of pests[2] especially those that are seed- and soil-borne (7). The informal sector is the main option through which most smallholder potato farmers obtain potato planting materials (8). This low availability is caused by a number of factors which include high costs of seed certification, low uptake of seed multiplication technologies (such as aeroponics, hydroponics, and tissue culture) and low volumes of basic seed for bulking. The associated causes of high cost of seed certification include low numbers of seed inspectors and lack of access to high modern speed inspection equipment while the low uptake of seed multiplication technologies is partly attributed to the cost of putting up the infrastructure and the high levels of expertise required to operate them. The low availability also has a direct effect on usage (Section 1.3.2).

1.3.2 Low Usage of Certified Seed

Low usage is partly attributed to the low availability as explained above (Section 1.3.1), but is also caused by high prices, poor distribution networks, lack of enough information about certified seed and limited availability of seed for preferred varieties. Apart from not being able to meet the current demand for certified seed, potato seed companies are based in Kirinyaga, Meru, Nairobi, Nakuru, and Nyahururu counties making it expensive for farmers from other potential counties to access seed at a manageable cost (purchase and transportation). Registered seed companies include KALRO - Tigoni and Kirinyaga Seeds in Kiambu; Agrico East Africa Ltd and Syngenta East Africa Ltd in Nairobi; Agricultural Development Corporation (ADC) - Molo, Charvi Investment, Singus Enterprises, and Starlight Cooperative Society in Nakuru; Kisima and Savannah Fresh Hort. Farmers' Cooperative Society Ltd in Meru. KALRO-Tigoni, ADC-Molo and Kisima Farm Ltd are the suppliers of basic seed for bulking of Kenyan varieties. Agrico East Africa also imports basic seed from the Netherlands for varieties bred outside Kenya.

1.3.3 High Pest Incidence

Pests contribute the biggest yield losses in the potato sector having been estimated to cause loses in the range of 30-40% with the potential to increase beyond 80% (9). Pests (both seed- and soil-borne) are mainly spread through using infested planting materials especially from the informal seed sector as explained in Section 1.3.1. Other factors that contribute to spread include inadequate knowledge on pest management, inadequate capacity to undertake potato pest diagnosis, poor knowledge of pest-free lands for seed multiplication, poor access to improved varieties and continuous

[2] **Pest** is used within the context of the International Plant Protection Convention (IPPC) and refers to any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (ISPM Number 5). Pathogenic agents include bacteria, fungi, oomycetes, phytoplasma, viruses and viroids while animals include arthropods, molluscs and nematodes.

cultivation of land. Inadequate knowledge on pest management is attributed to poor identification of pests by both farmers and extension officers yet without the right diagnosis, it is impossible to offer affordable actionable advice. The poor access to improved varieties may be attributed to poor usage of certified seed which results into persistent use of older varieties with planting materials mainly obtained from the informal sector. Further to this, potato is a key crop in the traditional production areas, hence the land is continuously cultivated to grow the crop. This leads to build-up of pests especially soil-borne pests such as *Ralstonia solanacearum*, the cause of brown rot (also referred to as bacterial wilt). Lastly, low usage of agro-inputs (such as pesticides, both organic, inorganic and biologicals) and poor agricultural practices (such as abuse of crop rotation regimes) also contribute the observed high pest incidences.

Pests reported to affect potato in Kenya are briefly explained below.

- **Insects** include potato tuber moth (*Phthorimaea operculella*), potato aphid (*Macrosiphum euphorbiae*), cotton aphid (*Aphis gossypii*), green peach aphid (*Myzus persicae*) and black bean aphid (*A. fabae*) (10, 11). *P. operculella* is the most destructive insect reported in the Sub-Saharan Africa (SSA) region including Kenya (12) while aphids are known to vector many diseases especially viruses (13). Minor pests include armyworms, cutworms and white grubs.
- **Fungi and Oomycete** include *Alternaria solani* (fungal), the cause of early blight and *Phytophthora infestans* (oomycete), the cause of late blight. Both pathogens affect other solanaceous crops especially tomato (*Solanum lycopersicum*) which is also widely grown in the same areas potato is grown providing year round source of inoculum. *P. infestans* is one of the most important pathogenic organisms affecting potato globally and Kenya is not exception (10, 14, 15).
- **Bacteria** include *R. solanacearum* (10, 16), and species belonging to the genus *Pectobacterium* (17) which cause blackleg.
- **Viruses** reported to cause diseases include Potato Leaf Roll Virus (PLRV), Potato Virus A (PVA), Potato Virus M (PVM), Potato Virus S (PVS), Potato Virus X (PVX) and Potato Virus Y (PVY) (10, 11, 18). Aphids transmit PLRV persistently but other viruses non-persistently. PVY is transmitted by at least 50 different aphid species. Loses attributed to these viruses vary between 10-40% in single infections but can be damaging in combination with yield losses reaching in excess of 80%. This synergism has been reported between PVX and PVA, PVX and PVY. PLRV and PVY individually form synergism with other viruses. However, PVY and PLRV are the most important and apart from losses in yield, they also greatly affect quality.
- **Nematodes** causing damage include the root knot nematode (*Meloidogyne incognita*) (10, 19) and recently, Potato cyst nematode (PCN) and Potato tuber nematode (PTN) (20, 21). There are two species of PCN, *Globodera rostochiensis* (yellow) and *G. pallida* (white) and two of PTN, *Ditylenchus destructor* and *D. dipsaci* (20, 21). Infection by *M. incognita* increases *R. solanacearum* severity (19).

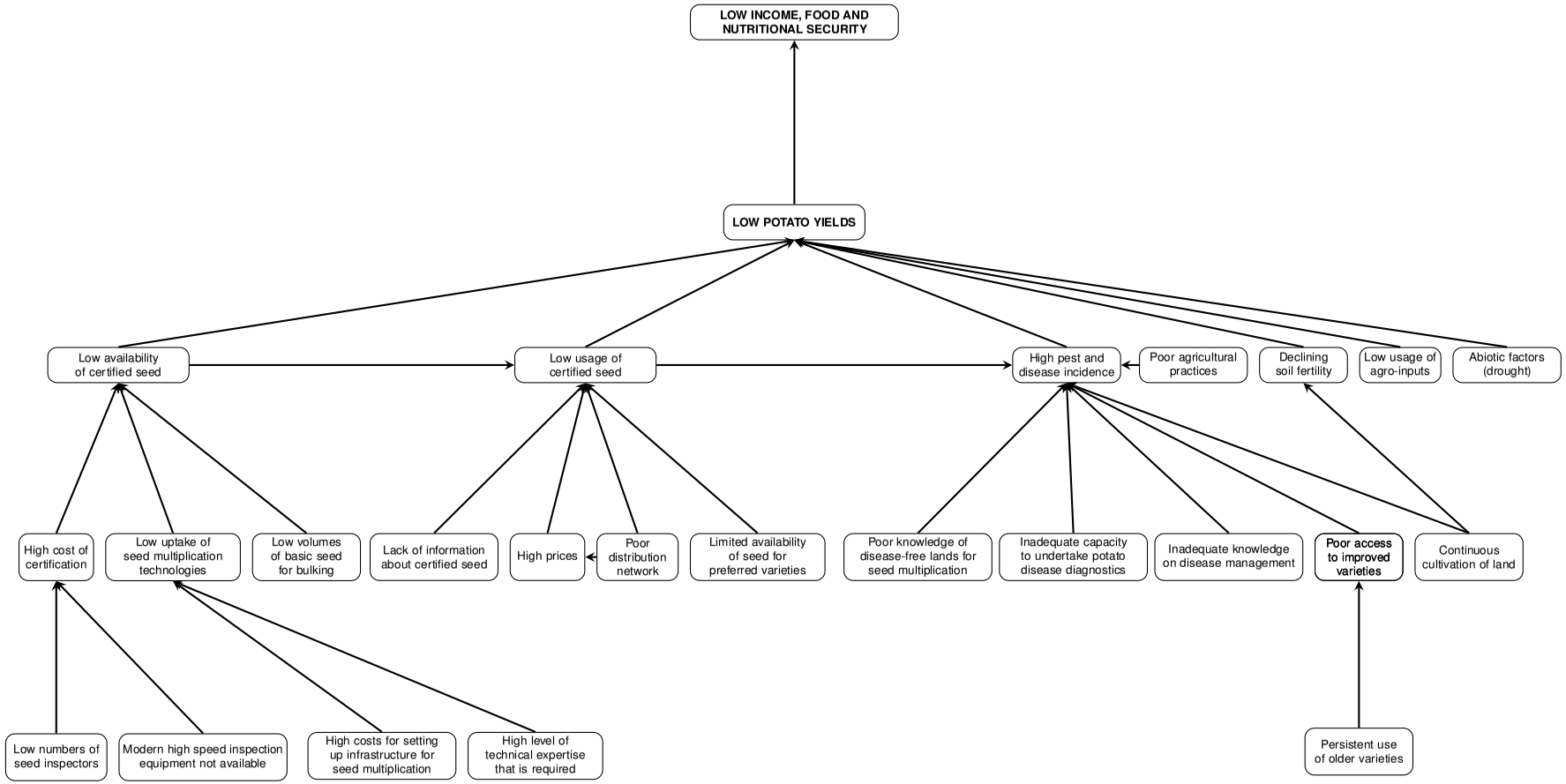


Figure 1.4: Factors causing low potato yields in Kenya. Source: This study

1.3.4 Additional Factors

Apart from resulting in high pest and disease incidences, continuous cultivation of land causes decline in soil fertility and the inability to afford agro-inputs (fertilizers) makes correction of this impossible. Lastly, potato production is widely rain-fed with minimal irrigation mostly reported in the Mt. Kenya region (22, 23). This affects year round production but also drought decimates potential yields.

1.4 Potato Diseases Surveillance

A series of meetings focusing on pest challenges decimating potato production in Kenya were conducted in 2019. These meetings brought together various actors in the potato value chain under the auspices of KEPHIS. A disease surveillance programme in the potato value chain whose main aim is to help the regulatory authorities in Kenya in disease monitoring was suggested. This will ensure that pests and diseases are detected early before spreading and seed regulatory practices are aligned with emerging risk factors. This will lead to increased awareness of the country's pest status, better pest prioritization and increased investments in critical pest risks. This will potentially improve pest management practices of authorities and market actors, drive increased availability of quality seed hence improving potato productivity, food security and incomes.

Therefore, in June 2019, a potato diseases surveillance planning meeting that brought together a number of actors in the potato value chain was held at KEPHIS headquarters following a series of meetings. Objectives of this meeting were;

i. Tap on technical knowledge of the invited stakeholders and evaluate technical issues in the context of Kenya's potato sub-sector.
ii. Examine ways of availing to farmers, as much as possible, disease free potato planting material to help increase productivity.
iii. Explore modalities of how item (ii) above can be achieved; considering prevalence of major disease threats and development of survey protocols the for some of them
iv. Agree on the roles of different institutions in the whole surveillance process, the scope of surveillance activities and time frames for surveillance work especially roles of KEPHIS and CABI, costing of activities, prioritizing organisms to target in the surveys.

KEPHIS presented a list of priority organisms identified as regulated pests in seed potato, from both the quarantine and the regulated non-quarantine perspectives. The organism included; the bacterial pathogens, *Clavibacter sepedonicus*; *Dickeya* and *Pectobacteria* species; the oomycete, *Rhizoctonia solani*); viruses (All strains of potato virus Y); and the nematodes, *G. rostochiensis*, *Ditylenchus disaci* and *D. destructor*. The nematode, *G. pallida* was ruled out as it has only been found in one sample in one field and upon repeated sampling, presence could not be confirmed. Although, the ultimate and long-term aim would be to have all organisms covered in the surveillance programme; constraints related to funding necessitated conducting the exercise in phases. Therefore, *C. sepedonicus*; *Dickeya* and *Pectobacteria* species

were considered for **Phase 1** while the rest for **Phase 2**. Surveillance to be conducted in selected major potato growing counties and a few other counties with potential to produce disease free planting material and expand potato production.

Counties to include in the surveillance exercise were selected based on three criteria described below.

- The county should be among those leading in potato production.
- The county should have a high potential to produce disease free planting material as well as high potential to expand production of ware potato.
- The county should have representative agro-ecological zones and hence enabling pest expression needed for collection of suitable samples.

Based on the above guidelines; **Elgeyo Marakwet**, **Meru**, **Nakuru**, **Narok**, **Nyandarua** and **Trans Nzoia** counties were selected (Figure 1.5). The selected counties have been host to a number of studies regarding potato pest status. For instance, studies by Kamau et al. (17) and Onkendi et al. (24) in the counties of Elgeyo Marakwet, Nakuru, Narok and Nyandarua established the presence of *P. carotovorum*, *P. brasiliense* and *P. wasabiae* (now *P. parmentieri*). The viruses PLRV, PVA, PVM, PVS, PVX and PVY were confirmed to be present in the counties of Meru, Nakuru, Narok, Nyeri and Nyandarua through studies conducted by Muthomi et al. (11, 18) and Were et. al. (10). Recently, presence of the *G. rostochiensis* (yellow) and *G. pallida* (white) were confirmed in Kenya through surveys conducted in Nyandarua (20, 25).

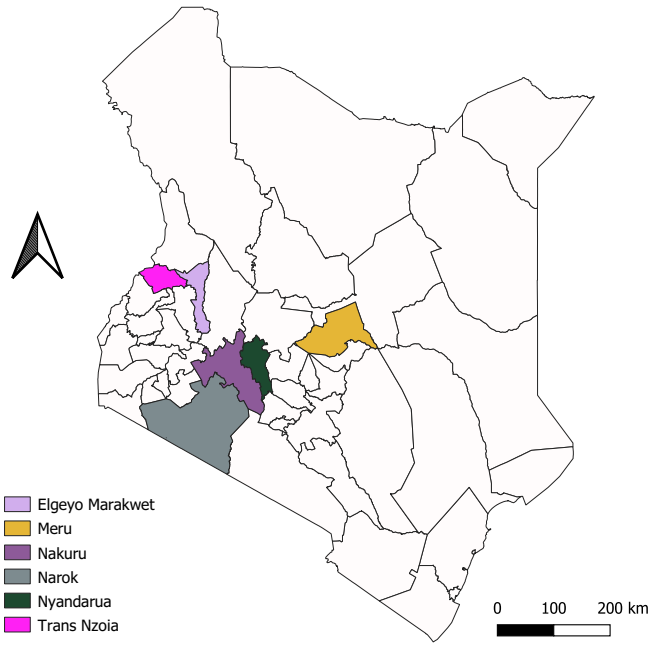


Figure 1.5: Counties where the disease surveillance exercise was conducted

The key objectives of the surveillance exercise included;

- Develop the surveillance protocol in line with international standards.
- Develop a survey plan in collaboration with key stakeholders such as KEPHIS and KALRO to maximise ownership of methodology and results.
- Determine the presence and distribution of bacteria that incite blackleg and soft rots (*Dickeya* sp. and *Pectobacterium* sp) and bacterial ring rot (*C. sepedonicus*).
- Enable prioritization of regulatory actions needed in interventions as part of official controls in seed multiplication and supply systems for Kenya.
- Support objective analysis of the current regulatory framework for certification of seed potato and develop / apply control/prevention measures necessary for quality assurance elements of seed health management strategy.
- Generate data and develop information that spell out risks and mitigation measures in seed supply systems (production, multiplication and distribution) for industry actors and farmers.

A horizon scanning assessment conducted in 2018 by CABI with other stakeholders in the plant health system including KEPHIS based on an adapted procedure of Sutherland et al. (26) and Roy et al. (27) highlighted *C. sepedonicus* and some of the Soft rot *Pectobacteriaceae* which included *D. dadantii*, *D. dianthicola*, *D. solani*, *D. zeae*, *P. atrosepticum*, and *P. parmentieri* as a high risk to Kenya's agricultural sector. Other pathogenic organisms important to the potato value chain that were highlighted include potato spindle tuber viroid, potato mop-top virus.

2

Target Species

2.1 *Clavibacter sepedonicus*

Clavibacter sepedonicus (28) (formally *C. michiganensis* subsp. *sepedonicus* (29, 30)) is the major cause of the vascular disease commonly referred to as Bacterial Ring Rot (BRR). It is a gram-positive rod-shaped, aerobic non-sporulating plant-pathogenic bacterium which affects both aerial stems and tubers (31). *C. sepedonicus* is largely restricted to an endophytic lifestyle, proliferating within plant tissues and incapable of persisting in the absence of plant material (32). It can however survive on dry materials such as walls, packaging materials and machines. It may remain latent in symptomless foliage, stems and tubers. All potato cultivars can serve as latent carriers, some cultivars however, are more likely to remain symptomless upon infection (33). The disease has a quarantine status and a zero tolerance in the seed potato industry in most countries including Kenya (34). *C. sepedonicus* has not yet been reported in Kenya. Field symptoms as presented in Figure 2.1 become visible only from mid to late season and include;

- Wilting is a key but not very specific symptom and in symptomatic plants, it occurs in lower leaves. It is usually slow, initially limited to the leaf margins which often curl upwards. Interveinal areas become pale green to yellowish and develop necrotic areas.
- Young infected leaves often continue to expand, though less so in the infected zones creating odd-shaped leaves.
- Symptoms may occur on a few stems and proceed upwards from the lower leaves until the entire stem is wilted resulting in severely infected plants dying prematurely.
- Heavily infected tubers may yield plants that develop rosette-like symptoms characterised by short internodes and reduced size of tuber. Such plants are occasionally stunted.
- Cutting a cross-section of lower stems, results in some cases exudation of a white ooze.
- Symptoms may be obscured by or confused with other wilts and foliage diseases, natural senescence and mechanical damage making them easily missed during field inspections.
- Pathogens for which symptoms may be confused include *R. solanacearum*, *Phoma*

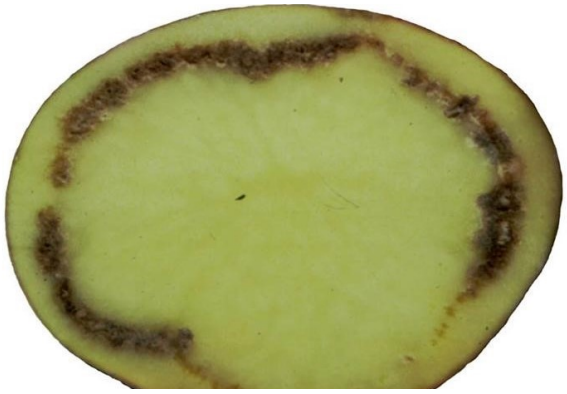
exigua var. *foveata*, and some saprophytic bacteria. Also *Dickeya* spp. and *Pectobacterium* spp. may cause similar leaf and wilt symptoms but usually with browning or blackening of the stems.

- Tuber symptoms may be confused with but differ from those caused by *R. solanacearum*.
- In the early stages, the rotted tissues usually remain cream-colored and by pressing the vascular tissue cream-colored slime with a cheese-like consistency appears, as opposed to the appearance, without pressing of a slimier ooze observed in brown rot. The rots however, does become discoloured as secondary invaders establish.
- External tuber symptoms, in severe cases may appear as reddish to brown blotches and/or surface cracks.

BACTERIAL RING ROT DISEASE OF POTATO

Early season dwarf rosette symptom
Credit: Credit: Ontario CropIPM

Yellowing of interveinal areas
Credit: Ontario CropIPM



Transverse cut of a bacterial ring rot infected tuber
Credit: Solke H. De Boer

A creamy or cheesy exudate forced from the vascular tissue when the tuber is squeezed
Credit: Neil Gudmestad

Figure 2.1: Symptoms displayed in leaves and tubers of potato plants affected by *C. sepedonicus*

2.2 *Pectobacterium* and *Dickeya* species

Species of bacteria reported in the genera *Dickeya* and *Pectobacterium* are known to cause soft rots in many plant hosts including *S. tuberosum* (35–38) but have also been isolated from aquatic environments (39–41). In *S. tuberosum*, they cause blackleg in plants (field) and soft rots in tubers (in field, during storage and transport) (42, 43). The two genera were originally classified under the genus *Erwinia* with the species *E. carotovora* subsp. *atroseptica*, *E. carotovora* subsp. *betavasculorum*, *E. carotovora* subsp. *carotovora*, *E. carotovora* subsp. *odorifera*, *E. carotovora* subsp. *wasabiae*, *E. cacticida* and *E. chrysanthemi* but Hauben et al. (44) proposed transfer of all these species to the genus *Pectobacterium* resulting in the species, *P. carotovorum* subsp. *atrosepticum*, *P. carotovorum* subsp. *betavasculorum*, *P. carotovorum* subsp. *carotovorum*, *P. carotovorum* subsp. *odoriferum*, *P. carotovorum* subsp. *wasabiae*, *P. cacticidum* and *P. chrysanthemi* (later elevated to *Dickeya* (45)). *Dickeya* and *Pectobacterium* were originally classified under the Family *Enterobacteriaceae* but have since been moved to the Family *Pectobacteriaceae* and are now collectively grouped under the Soft rot *Pectobacteriaceae* (SRP) instead of Soft Rot *Enterobacteriaceae* (SRE) (46). Plants may be infected and tubers contaminated by more than one bacterial species (47). The main virulence determinants of SRP are pectolytic enzymes secreted through the type II secretion system however, the *cfa* gene cluster, type III and IV secretion systems have also been shown to contribute to pathogenicity (48, 49). The genus *Pectobacterium* is comprised of 18 species while *Dickeya*, 12 species (50) which are concisely explained in Sections 2.2.1 and 2.2.2. Species delineation of SRP has been conducted through 16S rRNA sequence analysis (51–53), DNA-DNA hybridization (DDH) (wet-lab or digital[3]) (51, 55, 56), average nucleotide identity (ANI) values (56), multilocus sequence analysis (MLSA) using various housekeeping genes (37, 38, 52, 53, 55, 57) and analysis of utilization of various carbon sources (55, 56, 58, 59). Housekeeping genes used include *acnA*, *atpD*, *carA*, *icd*, *gapA*, *mdh*, *mtlD*, *pgi*, *recA*, and *rpoS*. Some of the carbon sources analysed include, 1-O-methyl-β-D-glucopyranoside, 1-O-methyl-α-d-glucopyranoside, l-alanine, cellobiose, d-galactose, gluconic acid, inulin, lactose, maltose, d-mannose, melibiose, palatinose, raffinose, and trehalose.

2.2.1 *Pectobacterium* species

P. actinidiae (formerly *P. carotovorum* subsp. *actinidiae* (56) was isolated from *Actinidia chinensis* (yellow kiwifruit) (37). *P. aquaticum* is a separate species of strains isolated from waterways (53). *P. oderiferum* (56) (formerly *P. carotovorum* subsp. *odoriferum* (36)) has been isolated from *Abelmoschus esculentus* (okra), *Allium ampeloprasum* (leek), *Apium graveolens* (celery), *Beta vulgaris* (sugar beet), *Brassica rapa* (Chinese cabbage), *Cichorium intybus* (chicory), *Cynara scolymus* (artichoke), *Hyacinthus orientalis* (hyacinth), *S. tuberosum* (36, 60). *P. aroidearum* is a species elevated from *P. oderiferum* (38) and has previously been isolated from *Ornithogalum dubium* (sun star), *S. tuberosum*, *Saccharum officinarum* (sugarcane), and *Zantedeschia aethiopica* (calla lily). (38). *P. atrosepticum* (51) (formerly *P. carotovorum* subsp. *atrosepticum* (58) is reported almost exclusively on *S. tuberosum* (61). *P. betavasculorum* (51)

[3] Digital DDH is an *in silico* method to replicate the wet-lab DDH as closely as possible (54)

(formerly *P. carotovorum* subsp. *betavasculorum* (62) is hosted on *B. vulgaris* (63, 64). *P. brasiliense* (56) (formerly *P. carotovorum* subsp. *brasiliense*) is a highly aggressive species causing severe infections on *S. tuberosum* in tropical and subtropical regions. *P. cacticidum* (formerly *P. cacticida*) affects various species of cactus and has been isolated from *Stenocereus gummosus* (sour pitaya), *Acanthocereus pentagonus* (triangle cactus), *Carnegiea gigantea* (Saguaro), *Cylindropuntia fulgida* (jumping cholla), *Ferocactus wislezenii* (fish hook barrel), *Opuntia ficus-indica* (barbary fig), *Opuntia stricta* (prickly pear), *Opuntia phaeacantha* (desert prickly pear), *Stenocereus thurberi* (organ pipe cactus) but has also been observed to cause soft rots in *S. tuberosum* slices (35).

P. carotovorum (56) (formerly *P. carotovorum* subsp. *carotovorum* (51)) affects a wide range of hosts worldwide including *S. tuberosum* (65, 66). *P. fontis* was elevated from *P. carotovorum* and strains in this species were isolated from waterfalls (67). *P. parmentieri* was elevated from *P. carotovorum* and strains from this species are known to cause soft rots and blackleg in *S. tuberosum* (68). *P. wasabiae* (formerly *p. carotovora* subsp. *wasabiae*), first isolated from diseased rhizomes of Japanese horseradish (*Eutrema wasabi*) (69) and later from *S. tuberosum* plants and tubers (70–74) was amended and incorporated into *P. parmentieri* (75). It was originally a separate recognised species in the genus *Pectobacterium* (50). *P. parvum* isolated from *S. tuberosum* stems, was originally classified as *P. carotovorum* subsp. *carotovorum* but recently elevated to a new species that has a *Salmonella* SPI-1-like type III secretion system and low virulence (76). *P. peruviense* isolated from *S. tuberosum* tubers cultivated at high altitudes was originally classified as *P. carotovorum* subsp. *carotovorum* but reclassified into a new species (77). *P. polaris* isolated from *S. tuberosum* was originally classified as *P. carotovorum* subsp. *carotovorum* but reclassified into a new species due to distinctiveness from other *Pectobacterium* species (78). *P. polonicum* is a new species isolated from groundwater sampled from a vegetable field. This species is distinct from the other *Pectobacterium* species but closely related to *P. punjabense* and *P. parmentieri* (79). *P. punjabense* isolated from *S. tuberosum*, is a new species which is closely related to *P. parmentieri* (59). *P. versatile* is a new species (56) that includes isolates originally classified as *Candidatus Pectobacterium maceratum* (80). This species was been isolated from water obtained from rivers, *Allium porrum* (wild leek), *Brassica oleracea*, *C. intybus*, *C. scolymus*, *Daucus carota* (carrot), *H. orientalis*, *Lactuca sativa* (lettuce), *S. tuberosum* (stems and tubers) and flowering plants (chrysanthemum, cyclamen, and primula) (56). *P. zantedeschiae* is a new species assigned to isolates recovered from *Z. aethiopica* (79) which were originally designated to *P. atrosepticum* (81, 82). All species except for *P. brasiliense*, *P. carotovorum*, *P. parmentieri* (17) have not been reported in Kenya. However, although *P. atrosepticum* has not yet been reported, CABI's Invasive Species Compendium (ISC) indicates its presence in neighbouring Tanzania (83).

2.2.2 *Dickeya* species

As previously indicated, all *Dickeya* originally belonged to the species *Erwinia chrysanthemi* (84) and were divided into six pathovars; *chrysanthemi*, *dianthicola*, *dieffenbachiae*, *parthenii*, *zeae*, and *paradisiaca* (85). Hauben et al. (62) proposed the transfer of *E. chrysanthemi* and its associated pathovars except *paradisiaca* to

the genus *Pectobacterium* becoming *P. chrysanthemi* while the pathovar *paradisiaca* was renamed *Brenneria paradisiaca*. Samson et al. (45), proposed elevation of the species *P. chrysanthemi* and *B. paradisiaca* to the genus *Dickeya* based on 16S rDNA sequence phylogeny and delineation of six species based on DNA-DNA hybridization studies as *D. chrysanthemi*, *D. dadantii*, *D. diffenbachiae*, *D. dianthicola*, *D. zeae* and *D. paradisiaca*. The species *D. dadantii* was later divided into two subspecies, *dadantii* and *dieffenbachiae*. The subspecies *diffenbachiae* was a reclassification of *D. diffenbachiae* based on DNA-DNA hybridization and MLSA (55). All the six species comprise strains isolated from various plant hosts, including both dicots and monocots but do not appear to harbour real host specificity (50). Studies by Pendron et al. (86) demonstrated diversity among *D. zeae* strains resulting in two distinct clades, one of which was later elevated to *D. oryzae* (87). The species *D. solani* (88), *D. fangzhongdai* (89), *D. poaceiphila* (90) for pectinolytic bacteria isolated from potato, *Pyrus pyrifolia* (pear) and *S. officinarum* respectively. The species *D. aquatica* (39), *D. lacustris* (40), and *D. undicola* (41) were proposed for *Dickeya* strains isolated from water. All *Dickeya* species have not been reported in Kenya however, CABI's ISC (83) indicates presence of *D. chrysanthemi* in Kenya although a substantive reference is not available.

2.2.3 Symptoms of Soft Rot *Pectobacteriaceae*

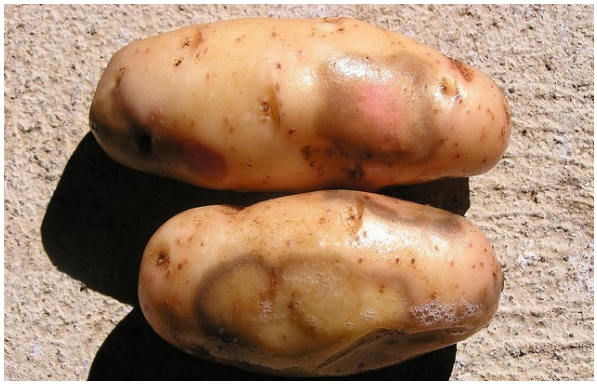
Field symptoms as presented in Figure 2.2 include;

- Blackleg may develop early (early blackleg) in the season after plants emerge and is characterised by stunted plants with yellowish foliage.
- The lower part of the below-ground stem of such plants is dark brown to black in colour and extensively decayed.
- The pith region is susceptible to decay and in infected plants, this decay may extend upward in the stem far beyond the tissue with externally visible symptoms.
- Blackleg may also develop late in the season and appears as a black discoloration of previously healthy stems, accompanied by rapid wilting and yellowing of the leaves. When the entire stem is affected, it decays and becomes desiccated leading to premature senescence.
- Black or brown discoloration of the stems always starts below ground and moves up the stem until the entire stem is black or brown and wilted.
- Tubers get infected via the stolon (which attaches the tuber to the plant) or via the soil by bacterium in the root zone spread from infected tissue or infested water.
- Tubers begin decaying at the stolon attachment site where the tissue becomes blackened and soft. The entire tuber may decay or the rot may remain partially restricted to the tissue inside the vascular ring (inner perimedullar).
- Potatoes stored under environments, with poor aeration such as in conditions of high humidity get a condition known as "hard rot" where lesions caused by the bacterium found around lenticels or mechanical damage becomes arrested on improving conditions.
- Once blackleg bacterium incites decay, growth of secondary bacteria often contributes to the decay process modifying symptomatology of the disease.

BLACKLEG AND SOFT ROT DISEASES OF POTATO

Black leg symptoms on the potato stems
Credit: OSU Extension Plant Pathology

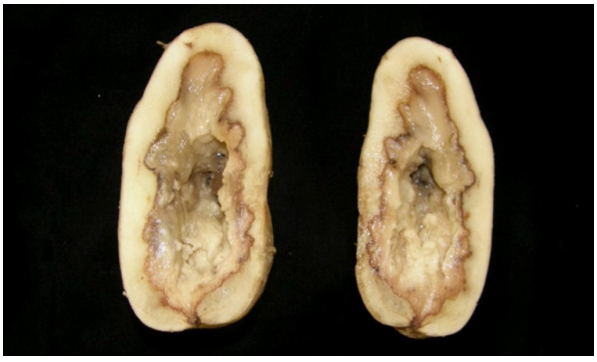
Black leg symptoms on potato stems
Credit: APS Biocontrol



Soft rot symptoms on outer skin of potato tubers
Credit: PlantVillage

Soft rot symptoms on outer side of potato tubers
Credit: American Phytopathological Society

Internal soft rot symptoms in potato tubers
Credit: AgroAtlas



Internal soft rot symptoms in potato tubers
Credit: www.spudman.com

Figure 2.2: Symptoms displayed in leaves, stems and tubers of potato plants affected by *Pectobacterium* and *Dickeya* species

3

Fact-finding Mission

3.1 Background

In November 2019, the project team, comprising four scientists; Joseph Mulema, Willis Ochilo and Duncan Chacha all from CABI and George Ngundo from KEPHIS undertook a fact-finding mission in the six counties (Elgeyo Marakwet, Meru, Nakuru, Narok, Nyandarua, and Trans Nzoia) selected for the surveillance exercise. The objectives of the fact-finding mission were four-fold;

- Explain the rationale of the potato disease surveillance exercise and share the surveillance protocol with the county officials
- Ascertain facts about potato production and associated pests and diseases (especially the target diseases) in the county
- Identify areas within the county (potato growing areas) to undertake the surveillance work
- Agree on the timelines and involvement of county personnel in the surveillance work.

The five day activity commenced from Meru county on the 11^{th} November 2019, proceeded to Nyandarua and Nakuru counties on the 12^{nd} November 2019, Trans Nzoia county on the 13^{th} November 2019, Elgeyo Marakwet county on the 14^{th} November ending in Narok on 15^{th} November county. The attendees of meetings were majorly from County governments' Department of Agriculture (DoA) who included CDA, County Horticultural Crops Officer (CHCO), County Crops Officer (CCO), Chief Officer (CO), Deputy County Director of Agriculture (DCDA), Data Officer (DO), Sub-county Agricultural Development Officer (SCADO), SCAO, Sub-county Crops Development Officer (SCCDO), Sub-county Crops Officer (SCCO), Sub-county Agricultural Production and Marketing Officer (SCAPMO), Soil and Water Conservation (SWC), and WAO.

3.2 Elgeyo Marakwet County

Potato is the leading cash crop in the county with a considerable segment of the population dependent on the crop as the main source of income. The crop is produced in 14 out of 20 wards in the county. Area under cultivation is estimated at 20,000 ha with

the annual production also estimated at 250,000 metric tonnes. The preferred variety by most farmers is Shangi since it matures after a short period and produces higher yields. The attendees of the meeting included; Rael Kipyego (CDA), Von Murgor (SCAO), Elizabeth Cheruto (SCAPMO), Charity Kosgei (SCCO) and Willy Rotich (SWC). The challenges mentioned included lack of clean seed; pests (especially *P. infestans* and *R. solanacearum*); continued use of extended bags; lack of proper storage facilities and drought because the production is mainly rain-fed. To address the challenge of lack of clean seed, the County government, annually sets aside funds for procurement of potato seed which is sourced mostly from the ADC farm in Nakuru. However, the county also seeks to establish a potato seed multiplication centre. They are also considering irrigation to reduce dependency on rain-fed production. All sub-counties (Keiyo North, Keiyo South, Marakwet East, and Marakwet West) were selected for the surveillance exercise. In Keiyo North, two wards (Kamariny and Kapchemutwa) were selected; Keiyo South, two wards (Kabiemit and Kaptarakwa); Marakwet East, one ward (Kapyego); and Marakwet West, two wards (Kapsowar and Lelan).

3.3 Meru County

Potato is one of the main food crops produced in the county, second only to maize. It is produced in eight out of the ten sub-counties with the area under production estimated at 6,600 ha. The county has only one company involved in seed production (Kisima Farm) hence unable to meet the demand in the region. The attendees of the meeting included Paul Mugwika (SCCO), Richard Muriithi (CHCO), Charity Kiritu (SCAO), Peninah Muthamia (SCAO), Peter Nguru (SCAO), Cornelius Miriti, (WAO), John Gathogo (WAO), Joseph M'tetu (WAO) and Godfrey Musyoka (WAO). Some of the potato production challenges mentioned included lack of clean seed; lack of proper storage facilities; degraded and over-used soils; pests (especially *P. infestans*, *R. solanacearum*, PCN and viruses); poor marketing; and continued use of extended bags. To address the challenge of lack of clean seed, the county supplies farmers with certified seed and also trains them on potato production best practices. About marketing, the county has formed seven potato cooperatives and one union to assist with marketing and processing. Lastly, on the issue of pests, the county desires to establish a baseline of all pests.Three sub-counties (Buuri, Imenti Central and Imenti South) which lead in potato production were selected for the surveillance exercise. In Buuri, four wards (Kiirua/Naari, Kibirichia, Kisima and Timau); Imenti Central, one ward (Abothuguchi West); and Imenti South, two wards (Nkuene and Abongeta West) were selected.

3.4 Nakuru County

Potato is one of the main food crops produced in the county, second only to maize. Nakuru is also one of the leading counties when it comes to seed production. Among the companies involved in seed production that are based in Nakuru is ADC, and Agrico East Africa Ltd. Annual potato production in the county is estimated at 541,000 metric tonnes produced on an estimated 95,000 ha by 20,000 smallholder farmers. The estimated value of the produce is KES 9.4 billion. Potato is produced throughout the year however, most of it is exported to other counties. The variety preferred by

most farmers is Shangi since it matures after a short period and produces higher yields. The attendees of the meeting included Stephen Mwangi (CCO), Hannah Oduor (CDA), Joseph Gaturuku (CHCO), Lynette Echesa (DO) and Alfred Waithaka (SCAO). The challenges mentioned included pests (especially *A. solani*, *P. infestans*, *R. solanacearum*, and PCN); lack of certified potato seed; lack of proper storage facilities resulting in post-harvest losses; erratic weather pattern; high cost of agro-inputs; poor marketing structures; fluctuating market prices; and continued use of extended bags. To address the issue of the lack of proper storage facilities, the county intends to promote adoption of post-harvest management technologies. On the issue of erratic weather patterns, the county intends to promote irrigation so as to reduce the dependency on rain-fed potato production. Seven sub-counties (Bahati, Gilgil, Kuresoi North, Kuresoi South, Molo, Njoro, and Sirikwa) were selected for the surveillance exercise. Bahati, one ward (Ndundori); Gilgil, two wards (Eburru and Elementaita); Kuresoi North, three wards (Kamara, Kiptororo, and Nyota); Kuresoi South, four wards (Amalo, Keringet, Kiptagich, and Tinet); Molo, four wards (Elburgon, Marioshoni, Molo and Turi); Njoro, three wards (Mauche, Mau Narok and Nessuit); and Sirikwa, two wards (Biashara and Naivasha) were selected.

3.5 Narok County

Narok targets to be a leading county when it comes to seed production. The attendees of the meeting included Benard Kimeto (CDA), Grace Mugo (CO) - Agriculture, and John Maina (WAO). The challenges mentioned included poor agronomic practices for both seed and ware potato; pests; limited supply of certified seed potato and continued use of extended bags. Three sub-counties (Narok East, Narok North, and Narok South) were selected for the surveillance exercise. In Narok East, two wards (Keekonyokie and Ildamat); Narok North (Melili and Oloropil); and Narok South, two wards (Sogoo and Sagamian) were selected.

3.6 Nyandarua County

Potato is the key enterprise contributing to food security, employment and income generation in county. Nyandarua contributes approximately 33% of the country's total produce. Area under production is estimated at 37,000 ha resulting in an estimated annual production of 550,000 metric tonnes. The most common varieties grown include Shangi, Rudolph, Caruso, Connect, Markies and Wanjiku. The county seeks to position itself as a leading producer of seed potato in the country. The attendees of the meeting included Joseph Wathinja (CDA), Daniel Muchiri (DCDA), Agnes Mburu (SCADO), Joseph Kimotho (SCCDO), John Macharia (SCCO), Mary Muigai (glsscco) and Robert Mwaniu (SCCO). The challenges mentioned that decimate production included pests (especially *P. infestans*, *R. solanacearum*, PCN, spider mites, and viruses); waterlogging; limited supply of certified seed; lack of markets and storage facilities; and poor agronomic practices for both seed and ware potato production. To address the issue limited certified seed, some farmers have ventured into apical cuttings while the county is also building a tissue culture laboratory. They also envisage that the Potato Regulation 2019 will address lots of the challenges in the entire value chain. All sub-counties (Kinangop, Kipipiri, Ndaragwa, Ol Joro Orok and Ol Kalou) were selected

for the surveillance exercise. In Kinangop, four wards (Magumu, Murungaru, North Kinangop and Nyakio); Kipipiri, three wards (Geta, Kipipiri and Wanjohi); Ndaragwa, three wards (Central, Kiriita and Shamata); Ol Joro Orok, three wards (Charagita, Gathanje and Weru); and Ol Kalou, three wards (Kanjuiri Ridge, Mirangine and Rurii) were selected.

3.7 Trans Nzoia County

Potato is produced under an estimated at 1,400 ha resulting in an estimated annual production estimated at 13,500 metric tonnes. The attendees of the meeting included Kenneth Kagai (CCO), Edward Osanya (CDA), Jacinta Waliaula (DCDA), Benard Owuori (SCADO), Namoi Mukusa (SCADO), Elizabeth Kariuki (SCAO), Francis Ng'ang'a (SCAO) and Stella Kimutai (SCAO). The challenges metioned included pests; erratic weather pattern; limited supply of certified seed. The county intends to venture into irrigation farming to reduce over dependency on rain-fed potato production. Three sub-counties (Cherangani, Endebess, and Saboti) were selected for the surveillance exercise. In Cherangani, two wards (Cherangani/Suwerwa and Makutano); Endebess, three wards (Chepchoina, Endebess, and Matumbei); and Saboti, two wards (Kinyoro and Saboti) were selected.

4

Materials and Methods

4.1 Sample Collection

Prior to the surveillance exercise, a list of farmers per ward in the respective sub-counties per target county, was received from the CDAs as had been agreed upon during the fact-finding mission (Section 3). The farmers were selected by the WAOs based on two criteria; the farm should have had a long history of potato production (at least three previous seasons) and had at least observed suspected cases of the target pathogens. We employed selective or targeted sampling (mentioned in ISPM 6 and described in ISPM 31) because the surveillance exercise focused on a host and pathogens deliberately targeted with the objective of detecting presence but not provide information about levels of infestation.

Therefore, samples were collected from plants showing symptoms associated with the target pathogens. Whole plant (includes leaves, stems and tubers) samples were collected and put in Khaki paper bags to protect them from direct sunlight. The collected samples were then placed in insulated containers (polystyrene boxes) which contained ice blocks to protect them from temperature extremes and shipped to KEPHIS within 24 h of collection. Soil samples were also collected and placed in plastic bags which were placed within Khaki paper bags. This was because blackleg and soft rot bacteria may survive in soil for between 1 week to 6 months, depending on environmental conditions such as soil temperature, moisture and pH, although survival can be longer if there are plant materials such as volunteers (42, 91). Soil was collected from all farm even where whole plants had been obtained. For farmers who met the criteria but had already harvested the crop, soil was a key sample in addition to plant debris, volunteer plants, and tubers if they were available. For tubers, up to 25 were randomly collected whether they displayed soft rot symptoms or not.

In case symptomatic plants were not observable, then simple random sampling (also described in ISPM 31) was employed to give equal probability in selecting samples. Randomness was achieved either by walking and examining hosts in a large zigzag pattern across the field. To avoid transfer of pests from farmer to farmer and plant to plant, disposable gloves were used between visiting different farms and sampling

different plants in the field. This was important especially were only asymptomatic plants were observable which prevented transmission of pests especially pathogenic organisms between plants during examination. In addition, the FAP also sterilized their shoes in a solution of 5% Sodium hypochlorite in between farmers' fields. This was key to avoid transmission of soil-borne pests especially *R. solanacearum*. To increase the chances of detection, three samples were collected per farm especially were no symptomatic plants were observed.

All samples were given unique codes (identifiers) derived from the county, sub-county and ward names and initials of farmers' names. The identifier consisted of a two-letter code for the county, three-letter codes for the sub-county and ward and two or three letter initials for the farmers' names (Table 4.1). The codes were set by selecting a combination of the first two or three consonants to ensure uniqueness unless they were few in which case a vowel was added either at the beginning or the end. Where sub-county and ward codes were similar, a second consonant that would create uniqueness in one was selected. Numbers were added to the farmers' initials if they were similar for farmers from the same county, sub-county and ward. For instance, sample MR-IMS-AGB-CM was from Meru county, Imenti South sub-county, Abogeta West ward and came from Chris Marete while sample MR-IMC-ABT-SM3 was from the same county, sub-county and ward but there were three farmers with the same initials.

The unique identifiers were also linked to detailed information collected about the farmer from whom the sample was collected as indicated in Section 4.3 and Appendix A. Prior to the exercise, all FAP received training at the NARL, Kabete in Nairobi. The objective was to ensure that the whole team understood the protocol, the symptoms and signs of the target pathogens, the procedure for sample collection, including hygienic measures, and how the integrity of the samples was supposed to be protected.

Table 4.1: Surveyed counties, sub counties and wards with their respective codes

County	Sub county	Ward
Elgeyo Marakwet (EM)	Keiyo North (KYN)	Kamariny (KMN)
		Kapchemutwa (KPC)
	Keiyo South (KYS)	**Kabiemit (KBM)**
		Kaptarakwa (KPT)
	Marakwet East (MRE)	Kapyego (KPY)
	Marakwet West (MRW)	Kapsowar (KPS)
		Lelan (LLN)
Meru (MR)	Buuri (BRI)	Kibirichia (KBR)
		Kiirua/Naari (KNA)
		Kisima (KSM)
		Timau (TMA)
	Imenti Central (IMC)	Abothuguchi West (ABT)
	Imenti South (IMS)	Abogeta West ABG)
		Nkuene (NKU)
Nakuru (NK)	Bahati (BHT)	Ndundori (NDN)
	Gilgil (GLG)	**Eburu (EBR)**
		Elementaita (EML)
	Kuresoi North (KRN)	Kamara (KMR)

Continued on next page...

County	Sub county	Ward
		Kiptororo (KPR)
		Nyota (NYT)
		Sirikwa (SRK)
	Kuresoi South (KRS)	Amalo (AML)
		Keringet (KRN)
		Kiptagich (KPG)
		Tinet (TNT)
	Molo (MLO)	Elburgon (ELB)
		Marioshoni (MRS)
		Molo (MLO)
		Turi (TRI)
	Naivasha (NVS)	Biashara (BSH)
	Njoro (NJR)	Mau Narok (MNR)
		Mauche (MCH)
		Nessuit (NSS)
Narok (NR)	Narok East (NRE)	Keekonyokie (KKN)
		Ildamat (ILD)
	Narok North (NRN)	Melili (MLL)
		Olokurto (OLK)
		Oloropil (OLR)
	Narok South (NRS)	Sagamian (SGM)
		Sogoo (SGO)
Nyandarua	Kinangop (KNG)	Magumu (MGM)
		Murungaru (MRG)
		North Kinangop (NKG)
		Nyakio (NYK)
	Kipipiri (KPP)	Geta (GTA)
		Kipipiri (KPR)
		Wanjohi (WNJ)
	Ndaragwa (NDR)	Central (CNT)
		Kiriita (KRT)
		Shamata (SHM)
	Ol Joro Orok (OLJ)	Charagita (CHR)
		Gathanje (GTH)
		Weru (WRU)
	Ol Kalou (OLK)	Kanjuiri Ridge (KNJ)
		Mirangine (MRN)
		Rurii (RRI)
Trans Nzoia (TN)	Cherangany (CHR)	Cherangani/Suwerwa (CHS)
		Makutano (MKT)
	Endebess (END)	Chepchoina (CHP)
		Endebess (END)
		Matumbei (MTM)
	Saboti (SBT)	Kinyoro (KYN)
		Saboti (SBT)

Although the wards were an indication by the county teams were the surveillance exercise could be conducted in the respective counties, 87.3% (55) of the total number (63) of wards were surveyed. The **RED** indicates the wards that were not surveyed and account for 12.7% (8) of the total number of wards.

4.2 Sample Processing

On arrival at KEPHIS, the samples were kept in cold storage (4^oC) but processed within 24 h. During processing, the table surfaces where sterilised with 70% ethanol in between samples to ensure no occurrence of cross contamination. Tools such as knives and scalpels were submerged in absolute (95%) ethanol and then exposed to a flame to burn-off excess alcohol. Disposable gloves were changed in between samples. All samples were cut on sterile paper towels which were also changed in between samples. Using the sterilised implements as indicated above, whole plant samples were separated into leaves, stems, roots and tubers. Tuber samples covered in soil were washed under running water. Then a portion that included both the stem-end and a portion of tuber peel (periderm) was removed (Figure 4.1). Tuber stem-end sections containing the core and tuber peels were used to detect SRPs in tuber samples. Evidence shows that SRPs can reach at very high concentration in the stem-end of the tuber but may also be found at higher incidence although low concentration on tuber periderms (92–94). Soil accompanying plant and tuber samples from each farm was measured in approx. 40 g portions. All separated portions were put in 50-mL falcon tubes and kept at -20^oC until needed for target pathogen isolation.

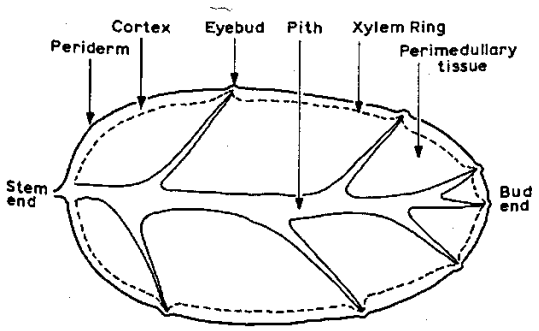


Figure 4.1: Longitudinal section of mature potato tuber. Demonstrates the stem-end of the potato tuber. **Source**: Keijbets, 1974 (95)

4.3 Sample Supporting Data

For all farmers from whom samples were collected, additional information important in putting the result about the sample in the right context was also obtained. These data were collected using a structured questionnaire (Appendix A) that had been programmed on the ODK platform and deployed on tablet computers. This allowed the utilisation of in-built checks on data validity that restrict the entry and submission of data that do not meet the required criteria. The data were received on the aggregate server in near real-time, random quality checks performed and feedback given to the data collection teams on the ground. This further enhanced the quality of data collected. Upon completion of the survey, data were downloaded from the aggregate server as Comma Separated Values (CSV) files, cleaned and analysed. Following processing of the plant tissue samples from which isolations were made, all the remaining tissue were incinerated. The unused soil samples were sterilised before disposal while petri dishes with media that had been used in pathogen isolation were autoclaved before disposal.

4.4 Isolation of Target Pathogens

4.4.1 *Clavibacter sepedonicus*

The samples (tubers or stems) were washed in running water to remove excess soil followed by surface sterilization in 5% Sodium hypochlorite solution for 5 min. The tissue were then macerated in a small volume (approx. 5-8 mL) of 50 mM phosphate buffer and left for 5-10 min for bacteria to ooze out into the solution. 100 μL of the supernatant was spread on to MTNA medium (Appendix C.5) and incubated at 23^{o}C. The plates were examined from 3 days and presumptive colonies transferred to NBY (Appendix C.11) or YGM (Appendix C.9) medium. Detailed protocol presented in Appendix E.

4.4.2 *Dickeya* spp. and *Pectobacterium* spp.

The test samples (tubers and stem) were washed under running tap water to remove excess soil but avoided breaking the skin. This was followed by surface sterilization with 0.5% Sodium hypochlorite for 5 min. The samples were then washed three times in sterile distilled water and finally air-dried. For symptomatic samples, the skin (stems) was cut open while for tubers, small portions were extracted to remove small amounts of tissue (approx. 0.1 g). This was done at the intersection of the diseased and healthy tissue (edge of lesion) using a sterile scalpel. Samples were cut on sterile paper towels, which where disposed of between samples as was the gloves. Some studies have shown that *Dickeya* sp. and *Pectobacterium* sp. can be found in the same field hence processing samples individually provides information on which pathogen is more prevalent. Therefore, even duplicate, triplicate or quadruplicate asymptomatic samples where processed and isolations made separately. The tissues were macerated in approx. 5-8 mL of sterile distilled water in a plastic petri dish and left for about 5 min to allow the bacteria diffuse out.

The extract from the homogenized sample was pippetted off. A 1 mL aliquot of the supernatant was removed and stored at -20^{o}C as a back-up stock. Another 100 μL of the supernatant was innoculated in D-PEM (Appendix B.14) and incubated under anaerobic conditions at 28^{o}C for 24 h. Isolations were made on selective diagnostic CVP medium (Appendix C.1 and C.2). For soil, all stones where removed and all aggregates broken up in small pieces. Approx. 20 g of soil were added to D-PEM in ratio of 1:3 (w/v) and incubated under anaerobic conditions as explained earlier. 100-200 μL of the supernatant of the enriched sample was then spread on to CVP plates which were incubated upside down at 28^{o}C for about 5-7 days. Because of the enormity of the samples that were processed, separate colonies or cavities were not picked instead approx. 1.5 mL of sterile water was added to each plate and washed to recover all surface growth. Around 1.3 mL was added to a 1.5-mL eppendorf and kept at -20^{o}C for further use while the remaining, approx. 500 μL added to another eppendorf and used in Section 4.6 for molecular diagnostic tests.

Following PCR confirmation, 100 μL from samples that were positive was spread on to Nutrient Agar (NA) (Appendix C.7) plates and incubated at 28^{o}C for 3 days. Well-spaced colonies were selected and streaked on to fresh NA plates. However, for

all crowded plates or those that carried characteristic saprophytic growth, a dilution series from 10^0 to 10^{-3} was made from the original sample. This ensured that colonies were well separated out and where there was saprophytic growth, saprohytes were diluted out leaving only the SRP. 100 μL of each dilution for each sample was then spread on to fresh NA plates and incubated as originally indicated. Alternatively, 100 μL from samples that tested positive were spread on to CVP plates and incubated as indicated. Colonies forming cavities were then selected and streaked on to fresh NA plates. Detailed protocol presented in Appendix F. However, for some samples

4.5 DNA Extraction

Pure bacterial colonies from a 24-h old culture grown on NA or YGM medium for *C. sepedonicus*; or for *Dickeya* and *Pectobacterium* species were picked with a sterile loop and suspended in 500 μL of sterile distilled water. 40 μL of Sodium Dodecyl Sulfate (SDS) (10%) and 8 μL Proteinase K (2 mg/mL) were added, mixed well and incubated for 1 h at 56^{o}C. 100 μL of 5 M Sodium chloride and 100 μL of CTAB were then added, mixed and incubated at 65^{o}C for 10 min. 500 μL of Chloroform:Isoamyl alcohol (24:1) were added, vortexed and centrifuged at 13,226 x *g* for 10 min to separate the phases. The aqueous phase was removed and transferred to a clean 1.5 or 2.0 mL microfuge tube. The Chloroform:Isoamyl alcohol extraction step was repeated if there were any carry over organic phase. The salt concentration was adjusted by adding 1/10 volume of Sodium acetate (0.5 M, pH 5.2). 2.5 volumes of ice cold ethanol (100%) was then added and incubated overnight at -20^{o}C. The mixture was centrifuged at 13,226 x *g* for 10 min at 4^{o}C and the supernatant carefully decanted. 500 μL of ice-cold ethanol (70%) were added, centrifuged at 13,226 x *g* for 10 min at 4^{o}C to wash the pellet. The supernatant was decanted and the pellet air dried for 60 min in a Lamina flow. The pellet of extracted DNA was resuspended in 100 μL Tris-EDTA (TE) buffer. The extracted DNA was stored at -20^{o}C until need for use. The purity and concentration of DNA was determined on a NanoDrop spectrophotometer (NanoDrop Technologies, Wilmington, Delaware). The detailed protocol is included in Appendix G. Preparation of buffers and solutions available in Appendix B.

4.6 PCR Assay

The PCR template used was either DNA that was isolated as explained above (Section 4.5) or directly from bacterial cells (colony). For bacterial colonies, bacterial cells were killed by heating at 92 ^{o}C for 15 min (**?**). PCR reactions were carried out in a total volume of 20 μL containing 1X PCR buffer (New England Biolabs, Ipswich, MA, USA), 0.8 μM of each primer (Table 4.3), 0.2 mM of each of the four dNTP (New England Biolabs, Ipswich, MA, USA), 1.25 unit of *Taq* DNA polymerase (New England Biolabs, Ipswich, MA, USA), and 2 μL (approx. 100 ng) of template genomic DNA or 3 μL of heat-killed bacterial cells. In each PCR reaction, negative and positive controls were included. The negative control comprised of sterile water used in the preparation of the PCR master mix while the positive control used depended on the pathogen species being diagnosed and consisted of DNA extracted from species obtained from the official culture collection at NCPPB (Table 4.2).

PCR amplifications were performed on an eppendorf Mastercycler Nexus gradient thermocycler (Eppendorf AG, Hamburg, Germany) using conditions indicated in Table 4.4 for the respective primer sets (Table 4.3). Following PCR amplification, the PCR products were subjected to electrophoresis on a 1.0% agarose gel in 1X TAE buffer stained with SafeView Classic^{TM} nucleic acid gel stain (Applied Biological Materials Inc., Richmond, BC, Canada) as advised by the manufacturer for 45 min at 100 V. A 100 bp DNA ladder (New England Biolabs, Ipswich, MA, USA) was loaded on one side of each gel in addition to the negative and positive controls and test samples. The gels were visualized under UV light and photographed using the Azure c200 Gel Imaging System (Azure Biosystems Inc. Dublin, CA, USA) to obtain digital images for each gel.

Table 4.2: Positive control strains of pathogenic bacteria used in this study

NCPPB number	Name of organism
3896	*Clavibacter sepedonicus*
3916	*Clavibacter sepedonicus*
4218	*Clavibacter sepedonicus*
4610	*Clavibacter sepedonicus*
3531	*Dickeya zeae*
3536	*Dickeya dadantii*
3881	*Dickeya dianthicola*
4479	*Dickeya solani*
3398	*Pectobacterium carotovorum*
3427	*Pectobacterium carotovorum*
4585	*Pectobacterium atrosepticum*
4609	*Pectobacterium brasiliensis*
4636	*Pectobacterium atrosepticum*
4642	*Pectobacterium brasiliensis*
4645	*Pectobacterium parmentieri*

Table 4.3: Specific primer sets for conventional PCR used in this study

Target organism	Primer name	Primer sequence (5′-3′)	Amplicon size (bp)	Reference
C. sepedonicus	Cms50F	CTATGACGCTCGCGGGTTGCTGTT	192	96, 97
	Cms50R	CGGCGGCGTCGTAGTGGAAAGTC		
C. sepedonicus	Cms72aF	CTACTTTCGCGGTAAGCAGTT	213	96, 97
	Cms72aR	GCAAGAATTTCGCTGCTATCC		
Pectobacterium sp.	Y1	TTACCGGACGCCGAGCTGTGGCGT	434	98
	Y2	CAGGAAGATGTCGTTATCGCGAGT		
Dickeya spp.	ECH1	TGGCGCGTCAGGAAGTTTAT	600	99
	ECH1′	TCACCGGTCAGGGTGAAGTT		
P. atrosepticum	ECA1	CGGCATCATAAAAACACG	690	100
	ECA2	GCACACTTCATCCAGCGA		
P. atrosepticum	Y45	TCACCGGACGCCGAACTGTGGCGT	439	99
	Y46	TCGCCAACGTTCAGCAGAACAAGT		
P. carotovorum	EXPCCF	GAACTTCGCACCGCCGACCTTCTA	550, 400	66, 101
	EXPCCR	GCCGTAATTGCCTACCTGCTTAAG		
P. brasiliense	BR1f	GCGTGCCGGGTTTATGACCT	322	102
	L1r	CA(A/G)GGCATCCACCGT		
P. parmentieri	PW7011F	CTATGACGCTCGCGGGTTGCTGTT	140	103
	PW7011R	CGGCGGCGTCGTAGTGGAAAGTC		

Primers originally used to test for presence of *P. wasabiae* were used to test for presense of the species *P. parmentieri*. The species *P. wasabiae* was amended and incorporated into *P. parmentieri* (75).

Table 4.4: Conventional PCR cycling conditions

Target organism	Primer pair	Step 1	Step 2	Step 3
C. sepedonicus	Cms50F/Cms50R	94^{o}C for 5 min	**35 cycles**: 94^{o}C for 1 min 60^{o}C for 30 sec 72^{o}C for 1 min	72^{o}C for 7 min
C. sepedonicus	Cms72aF/Cms72aR	94^{o}C for 5 min	**35 cycles:** 94^{o}C for 1 min 60^{o}C for 30 sec 72^{o}C for 1 min	72^{o}C for 7 min
Pectobacterium sp.	Y1/Y2	94 ^{o}C for 5 min	**35 cycles:** 94^{o}C for 30 sec 60^{o}C for 45 sec 72^{o}C for 1 min	72^{o}C for 7 min
Dickeya spp.	ECH1/ECH1′	94^{o}C for 5 min	**35 cycles:** 94^{o}C for 30 sec 60^{o}C for 45 sec 72^{o}C for 1 min	72^{o}C for 7 min
P. atrosepticum	ECA1/ECA2	94^{o}C for 5 min	**35 cycles:** 94^{o}C for 30 sec 65^{o}C for 45 sec 72^{o}C for 45 sec	72^{o}C for 7 min
P. atrosepticum	Y45/Y46	94^{o}C for 5 min	**40 cycles:** 94^{o}C for 30 sec 62^{o}C for 45 sec 72^{o}C for 1 min	72^{o}C for 7 min
P. carotovorum	EXPCCF/EXPCCR	94^{o}C for 5 min	**30 cycles:** 94^{o}C for 1 min 60^{o}C for 1 min 72^{o}C for 2 min	72^{o}C for 7 min
P. brasiliense	BR1f/L1r	94^{o}C for 5 min	**35 cycles:** 94^{o}C for 30 sec 60^{o}C for 45 sec 72^{o}C for 1 min	72^{o}C for 7 min
P. parmentieri	PW7011F/PW7011R	94^{o}C for 5 min	**35 cycles:** 94^{o}C for 1 min 67^{o}C for 45 sec 72^{o}C for 1 min	72^{o}C for 7 min

5

Field surveillance

5.1 Background

Prior to the surveillance exercise, all FAP received training at NARL, Kabete in Nairobi. The objective was to ensure that the whole team understood the protocol, the symptoms and signs of the target pathogens, the procedure for sample collection, and how the integrity of the samples was supposed to be protected. The surveillance exercise was conducted during the second (short rains) season of 2019. The exercise commenced on the 1^{st}, December 2019 and was planned to end on the 13^{th} December but continued to 20^{th} December due to unavoidable circumstances occasioned by bad weather especially in Elgeyo Marakwet, Meru, and Trans Nzoia. Three teams with each led by a team leader as demonstrated in Table 5.1 conducted the activity. Due to the fact that they are the leading potato producer in the country, all sub counties in Nyandarua were selected while in Nakuru all except four were selected for surveillance hence, all three teams at one time were in these two counties (Table 5.1).

Table 5.1: Teams of Field Assessment Personnel that participated in surveillance

Team	Name	Organisation	Counties
1	**Fernadis Makale (Leader)**	CABI	Meru
	Jackson Kilonzi	KALRO	Narok
	Loise Wangui	UoN	Nyandarua
	Mirriam Wanjiku	KALRO	Nakuru
2	**Duncan Chacha (Leader)**	CABI	Elgeyo Marakwet
	Patrick Pwaipwai	KALRO	Trans Nzoia
	Lucy Thungu	KEPHIS	Nyandarua
	Truphosa Viola	UoN	Nakuru
3	**George Ngundo (Leader)**	KEPHIS	Nyandarua
	Hilda Meso	UoN	Nakuru
	Faith Apwoka	KALRO	
	Jane Wanjiku	KEPHIS	

5.2 General Survey Results

All samples as indicated previously, were delivered to KEPHIS within 24 h of collection. Although only a small fraction of these samples was symptomatic for the target pathogens, isolations were attempted on all them. In total, 1,002 farming households were interviewed across the six counties. The majority of the farmers interviewed were from Nyandarua (32%), followed by Nakuru (27%), Meru (12%), Trans Nzoia (11%), Narok (9%) and lastly, Elgeyo Marakwet (9%).

Table 5.2: Number of farmers interviewed in all six counties

County	Farmers per county		Total
	Female	Male	
Elgeyo Marakwet	30	61	91
Meru	50	72	122
Nakuru	109	159	268
Narok	32	62	94
Nyandarua	147	170	317
Trans Nzoia	53	57	110
Total	**421**	**581**	**1,002**

Of the 1,002 farmers that were interviewed and from whom samples were collected, 421 which constitutes 42% were female and 581 which constitutes 58% were male (Table 5.2 and Figure 5.1).

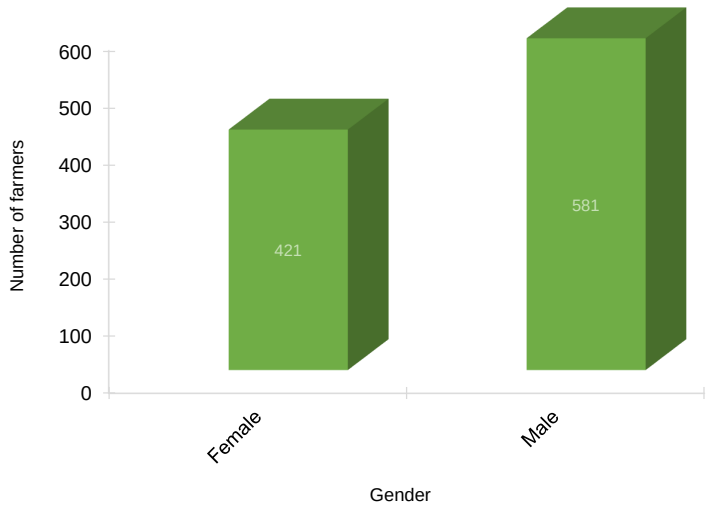


Figure 5.1: Proportion of female and male farmers interviewed from the six counties

In addition to disaggregation by gender, the interviewees were also disaggregated by age. Five age categories were considered which included <30 years, 31-35, 36-45, 46-55 and >55 years. The least category interviewed was the <30 year-category which comprised of 85 individuals constituting 8% of the total (Figure 5.3). This was followed by the 31-35 year-category, 127 (14.5%); 36-45 years, 248 (24.8%); >55 years, 254 (25.3%) and lastly, the 46-55 year-category which comprised of 288 constituting 28.7% (Figure 5.3).

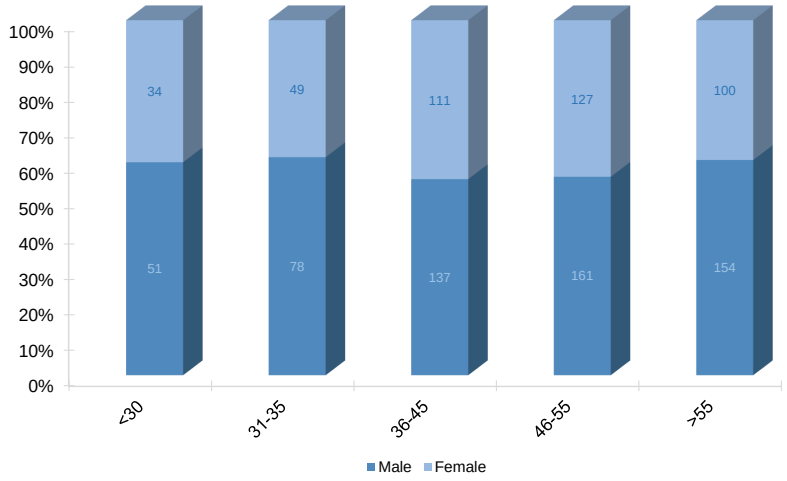


Figure 5.2: Disaggregation by age of all farmers interviewed from the six counties

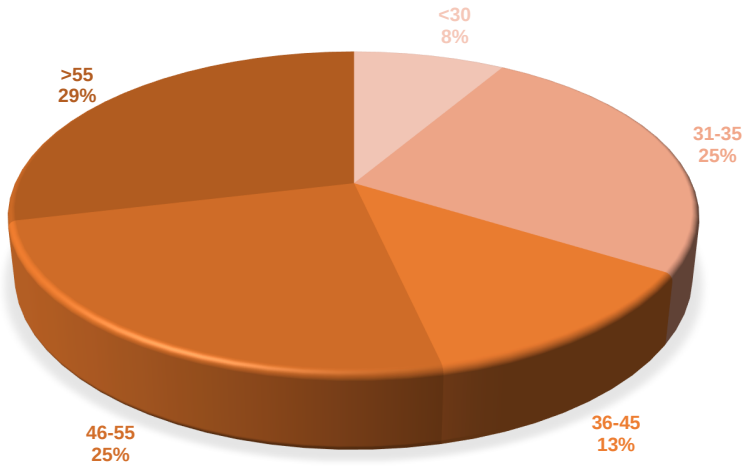


Figure 5.3: Proportion of the age categories of farmers from the six counties

Table 5.3: Crops grown by interviewed farmers in the six counties

Crop	Crop 1		Crop 2		Crop 3	
	Number	Acreage	Number	Acreage	Number	Acreage
Avocado					1	1.00
Bananas					2	2.00
Beans	11	15.95	64	99.78	142	142.00
Beet root					2	2.00
Black nightshade			1	2.00	1	1.00
Boma Rhodes	2	5.50	1			
Broccoli	1	0.25		1.00		
Butternut					1	1.00
Cabbages	15	12.25	132	139.91	100	100.00
Capsicum			1	1.00		
Carrots	5	2.75	33	56.98	58	58.00
Coffee			1	0.25		
Cowpeas			4	2.50	1	1.00
Flowers	1	1.00			2	2.00
French beans	2	2.50	6	3.50	10	10.00
Garden peas	6	9.50	72	71.98	89	89.00
Groundnuts			2	1.50	2	2.00
Kales	4	2.10	9	2.55	18	18.00
Maize	112	577.00	437	697.26	117	117.00
Millet					1	1.00
Napier grass			1	0.10	2	2.00
Oats	1	1.00	4	6.00	4	4.00
Onions			6	6.06	8	8.00
Passion fruit	1	0.60	1	0.25	1	1.00
Pearl millet	1	0.25	1	0.25	1	1.00
Pigeon pea	1	2.00			1	1.00
Plums					1	1.00
Potatoes	830	1,557.76	119	105.36	35	35.00
Pyrethrum	1	2.00				
Snow peas			5	5.75	3	3.00
Sorghum	1	0.50	1	20.00		
Spider plant			1	0.13		
Spinach					1	1.00
Sugarcane			2	1.00		
Sweet potatoes	1	0.50	2	1.75	1	1.00
Tea	1	0.80	1	1.50	1	1.00
Tomatoes	1	0.50	7	5.70	8	8.00
Tree Tomato			3	1.13	2	2.00
Wheat	4	36.00	13	199.63	11	11.00
None			72		375	
Total	**1,002**	**2,230.71**	**1,002**	**1,434.80**	**1,002**	**627.00**

Potato was selected by the majority of farmers (830, 83%) as the first-choice crop grown followed by maize (112, 11%) in the distant second however, maize was preferred by most farmers (437, 43.6%) as the second-choice crop after potato (Table 5.3). As a first-choice crop, potato also accounted for the biggest acreage followed by maize but came third after maize and cabbage when selected as second-choice.

Table 5.4: Use of crops selected by the interviewed farmers in the six counties

Crop	Crop 1			Crop 2			Crop 3		
	Food	Income	Both	Food	Income	Both	Food	Income	Both
Avocado									1
Bananas							2		
Beans	3	2	6	8	12	44	41	22	79
Beet root								1	
Black nightshade						1			
Boma Rhodes		2						1	
Broccoli			1	1					
Butternut								1	
Cabbages		7	8	7	72	53	16	41	43
Capsicum					1				
Carrots		3	2	1	19	13	3	19	36
Coffee					1				
Cowpeas					4			1	
Flowers		1						2	
French beans		2			6			9	1
Garden peas		4	2	5	32	35	12	37	40
Groundnuts						2		1	1
Kales			4	2	1	6	8	3	7
Maize	33	15	64	147	50	240	64	13	40
Millet									1
Napier grass				1				1	1
Oats	1			1	1	2	2	1	1
Onions				1	5		3	2	3
Passion fruit			1			1		1	
Pearl millet			1		1				1
Pigeon pea			1						1
Plums								1	
Potatoes	44	330	456	21	32	66	6	4	25
Pyrethrum		1							
Snow peas						5		3	
Sorghum			1			1			
Spider plant				1					
Spinach								1	
Sugarcane						2			
Sweet potatoes		1		1		1	1		
Tea			1			1		1	
Tomatoes			1		5	2		3	5
Tree Tomato						3			2
Wheat		4		1	10	2			6
Total	**81**	**372**	**549**	**198**	**252**	**480**	**158**	**169**	**294**

Whether selected as the first or second-choice crop, the majority of farmers in either category indicated they grew potato to cater for income and food followed by only income while the least (44) grew the crop solely for food.

Table 5.5: Potato varieties grown by interviewed farmers in the six counties

Potato variety	Choice		
	First	Second	Third
Arka	3	1	
Asante	16	24	5
Challenger		1	1
Destiny	2	3	
Dutch Robijn	33	18	3
Jelly	1	1	2
Kabale	10	6	
Kaumbire	6	9	1
Kenya Karibu			1
Kenya Mpya	1	1	1
Konjo		1	
Lenana		1	
Manitou		1	1
Markies	1	3	1
Mukorino			1
Nderamwana		2	
Nyayo		1	
Panamera		4	1
Purple Gold	1	1	
Rudolph			1
Shangi	899	29	
Sherekea	10	16	11
Stephen	2	5	2
Tigoni	11	2	
Umba		3	
Unica	3	6	
Voyager			3
Wanjiku			1
None	3	863	966
Total	**1,002**	**1,002**	**1,002**

In total, 28 varieties were grown with 16 selected as their first-choice (Table 5.5). Shangi was selected by the majority (899, 89.7%) followed in the distant second by Dutch Robijn (33, 3.3%). Four other varieties were selected at least by more than 10 farmers which included Asante (16, 1.6%), Tigoni (11, 1.1%), Kabale (10, 1.0%) and Sherekea (10, 1.0%).

The majority of farmers interviewed obtained potato planting materials from informal sources. A proportion of 34.1% (342) obtained planting materials from fellow farmers, 32.1% (322) used own saved planting materials and 19.9% (199) sourced

planting materials from both categories resulting in totals of 521 (51.2%) and 541 (54%) who sourced from fellow farmers and used own saved seed respectively. A small proportion of 5.1% (51) sourced planting materials from the market. Two of the farmers sourced planting materials from markets, fellow farmer or used their own saved materials (data not shown). Only 17.2% (172) of the farmers sourced seed from seed producers. Others sources indicated by 1.4% (14) of the farmers included the county government and NGOs. Note that some of the farmers selected multiple sources of planting materials resulting in the total figures not adding up to 1,002.

Table 5.6: Source of potato planting materials for farmers in the six counties

county	Source				
	Own-saved	**Fellow farmers**	**Market**	**Seed distributors**	**Others**
Elgeyo Marakwet	16	67	2	6	1
Meru	45	44	10	64	2
Nakuru	170	161	2	36	6
Narok	48	58	5	26	
Nyandarua	233	147	6	28	5
Trans Nzoia	9	64	26	12	
Total	**521**	**541**	**51**	**172**	**14**

The majority of farmers claimed using appropriate agronomic practices that improve crop productivity like recommended spacing (911, 90.9%), fertilizer application (987, 98.5%), scouting for pests (896, 89.4%), crop rotation (753, 75.1%), pest management (987, 97.1) and weeding (973, 97.1%). However, only 9.3% (94) irrigated their crops and 33.1% (332) used improved seed. Although 98.2% (984) did not mulch their crop, it is not an essential practice in potato production.

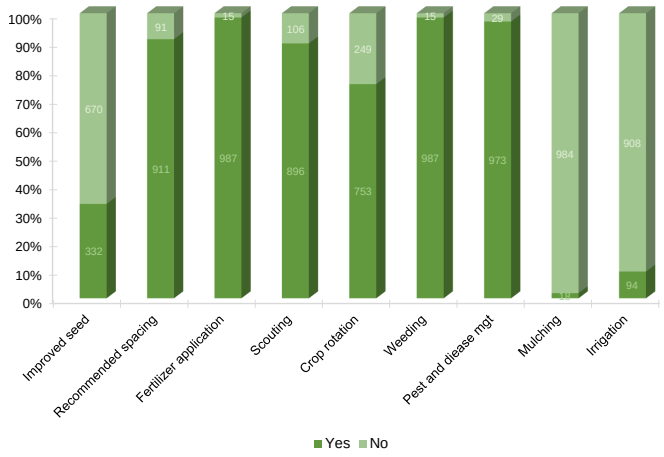


Figure 5.4: Agronomic practices implemented in potato production in the six counties

Crop rotation was reported to be used by 75% (753) of the farmers (Table 5.7) with maize (546, 54.5%) being the most rotated crop with potato followed by cabbage (226, 22.6%). Maize was also the second-choice crop after potato with cabbage coming in a distant third (Table 5.3) probably explaining the choice of these crops in rotations. Although a small fraction (5, 0.5%), some farmers rotated potato with tomato for which they share the some pests (Section 1.3.3) which is a bad agronomic practice that needs addressing through farmer training and awareness raising.

Table 5.7: Crops used in rotations with potato

Crop	county						Total	Proportion
	EM	MR	NK	NR	NY	TR		
Maize	41	87	177	75	129	37	546	54.49
Cabbages	7	66	48	33	67	5	226	22.55
Tomatoes			1	2	1	1	5	0.50
Carrots		17	9	9	54		89	8.88
Groundnuts			1	1	3		5	0.50
Beans	23	32	50	40	13	18	176	17.56
Garden peas	6	7	71	11	59	2	156	15.57
Cowpeas	2					1	3	0.30
Kales			2	2	6	5	15	1.50
Onions		2	1				3	0.30
Passion fruit	1		1		1		3	0.30
Wheat	2	11	1	5	1		20	2.00
French beans		14	1		4		19	1.90

- EM - Elgeyo Marakwet; MR - Meru; NK - Nakuru; NR - Narok; NY - Nyandarua; TN - Trans Nzoia

Irrigation was only reported by only 8.9% of the total (1,002) number of the farmers (Table 5.8). Sprinkler irrigation was the most used and mostly in Meru (66 of the 89; 74.1%) followed by Nyandarua (20 of 89; 22.5%) confirming reports of low usage and mostly around the Mt. Kenya region (Section 1.2).

Table 5.8: Methods of irrigation used

County	Method	
	Drip	Sprinkler
Elgeyo Marakwet		1
Meru	3	66
Nakuru		
Narok		
Nyandarua		20
Trans Nzoia		2
Total	**3**	**89**

The farmers were also asked which pests were managed with the various agronomic practices used. The majority (more than 50%) mentioned *A. solani* and *P. infestans* while more than a third mentioned *R. solanacearum*. White flies, cutworms and aphids were also mentioned although by a small fraction of farmers. The SRP especially *Pectobacterium* species which causes blackleg were mentioned by only approx. 2% of the farmers (20 of 1,002) while *C. sepedonicus* was not mentioned at all. All these results are presented in Table 5.9 below.

Table 5.9: Pests managed by the agronomic practices indicated in Figure 5.4

Biotic factor	county						Total	Proportion
	EM	MR	NK	NR	NY	TN		
Pathogenic organism								
P. infestans	70	76	248	83	280	55	812	81.04
A. solani	24	94	167	78	151		514	51.30
R. solanacearum	39	60	115	28	104	47	393	39.22
Viruses	2	8	3	1	15		29	2.89
SRP-associated	1	1	6	5	6	1	20	1.00
R. solani					1		1	0.10
Nematodes	4	3		7	9		23	2.30
Insects								
Whiteflies	25	9	20	14	9	13	90	8.98
Cutworms	16	8	26	1	30	7	88	8.78
Aphids	17	18	21	7	8	14	85	8.48
Thrips	8	30	3	2	4	1	48	4.79
Tuber moth	9	3	11	2	6	3	34	3.39
Leafminers		9			1		10	1.00
Spidermites	2	3	1	1	3		10	1.00
Ants			1			7	8	0.80
Chafer grubs					1	2	3	0.30
Caterpillar			2				2	0.20
Army worm					1		1	0.10
Grasshoppers					1		1	0.10
Others								
Millipedes	1		2		7		10	1.00
Rotting				1	4		5	0.50

- EM - Elgeyo Marakwet; MR - Meru; NK - Nakuru; NR - Narok; NY - Nyandarua; TN - Trans Nzoia

The majority (964, 96.2%) of farmers used their own experience for crop management (Figure 5.5) however, the main source of information on agronomic practices used included friends (566, 56.5%), radio (566, 56.5%), government extension (548, 54.8%). Demonstration (490, 48.9%) and agro-dealer (377, 37.6%) were selected by more than a third of the farmers. Plant doctors were the least source of information partly because Plant clinics are not widely distributed and not available on a daily basis like government extension, friends or agro-dealers.

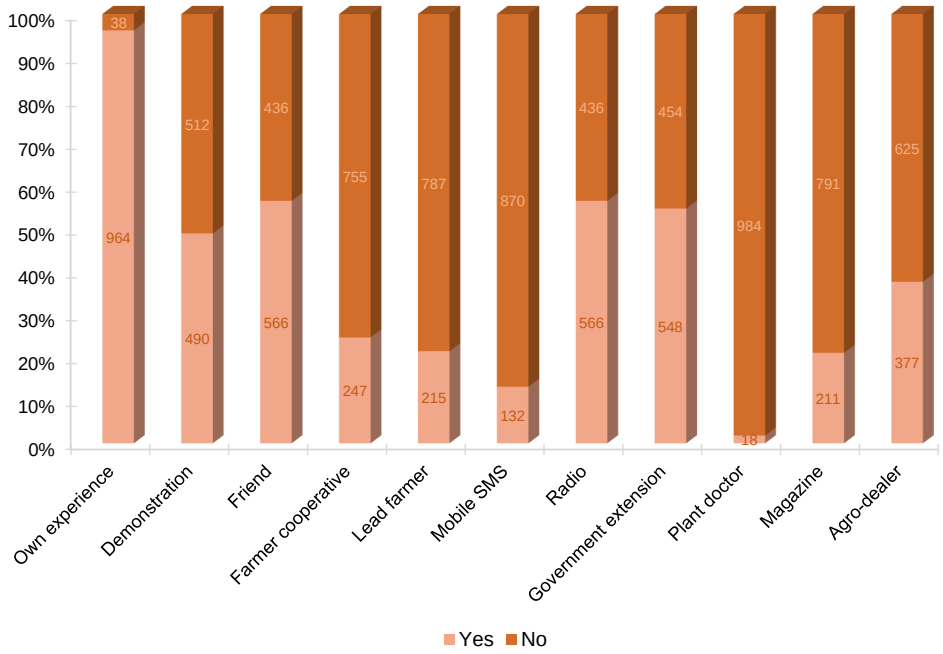


Figure 5.5: Sources of information for potato production and management of challenges in the six counties

Only seven (7) of the 1,002 indicated that they had observed BRR after being shown images depicting the disease (Figure 2.1) but it is also possible that they confused it with other abiotic or biotic plant health problems.

Table 5.10: Number of farmers who identified bacterial ring rot and action they took

County	Observation		Total	Action taken	
	No	Yes		Chemicals	Did nothing
Elgeyo Marakwet	90	1	91		1
Meru	122		122		
Nakuru	263	5	268	1	4
Narok	94		94		
Nyandarua	316	1	317		1
Trans Nzoia	110		110		
Total	**995**	**7**	**1,002**	**1**	**6**

Unlike bacterial ring rot, 17.0% (170) of the farmers observed presence of SRP-associated problems (blackleg in plants and soft rots in tubers). Nakuru and Nyandurua recorded the highest numbers of observations followed by Meru (Table 5.11). Trans Nzoia had the least number of observations. Most of the farmers did nothing especially for soft rots while others uprooted in case of blackleg. Interestingly, 15.3% (26 of the 170) of the farmers used chemicals to manage blackleg which indicates a gap in knowledge and information that has to be addressed. only 5 (approx. 3%) of the farmers reported cases of SRP-associated problems to extension.

Table 5.11: Number of farmers who identified SRP-associated diseases and action taken

county	Observation		Total	Action taken			
	No	Yes		Reported to extension	Chemicals	Uprooted	Did nothing
Elgeyo Marakwet	79	17	91	1	3	5	9
Meru	99	23	122	2	9	6	10
Nakuru	214	54	268	1	7	33	27
Narok	76	18	94		3	4	12
Nyandarua	262	55	317	1	4	23	36
Trans Nzoia	107	3	110			2	2
Total	**832**	**170**	**1,002**	**5**	**26**	**73**	**96**

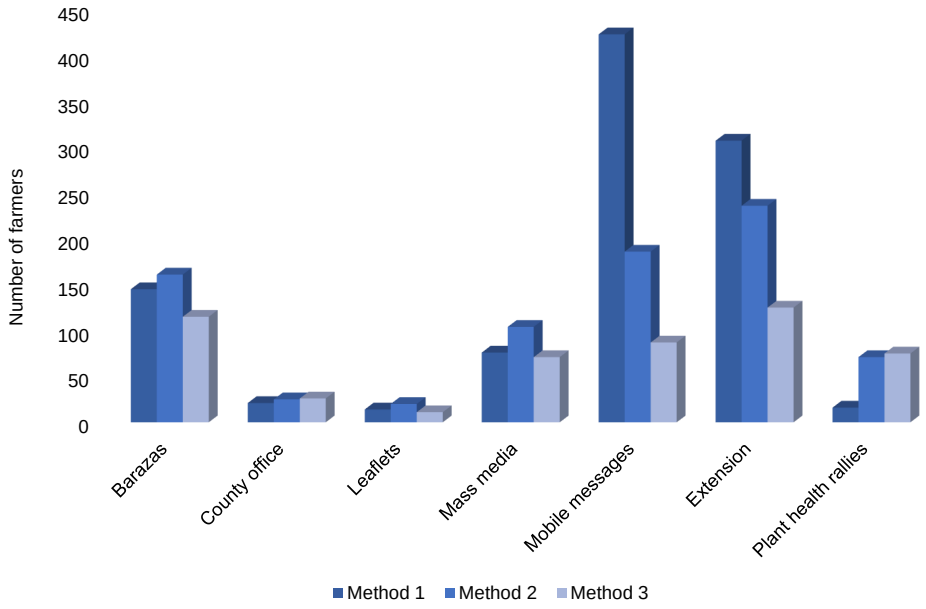


Figure 5.6: Method of choice for information dissemination in potato production in the six counties

In case of an outbreak of blackleg, soft rots and bacterial ring rot, the majority of farmers selected use of mobile messages followed by extension as their main method of choice for information dissemination (Figure 5.6).

5.3 Elgeyo Marakwet County

A total of 91 farmers (9.1% of all farmers) were interviewed from Elgeyo Marakwet county and samples obtained. These farmers came from sub-counties and wards that were selected by the WAOs and forwarded to CABI by the CDA. Seven wards from four sub-counties were selected, all of which were surveyed except for Kabiemit in Keiyo South (See Table 4.1).

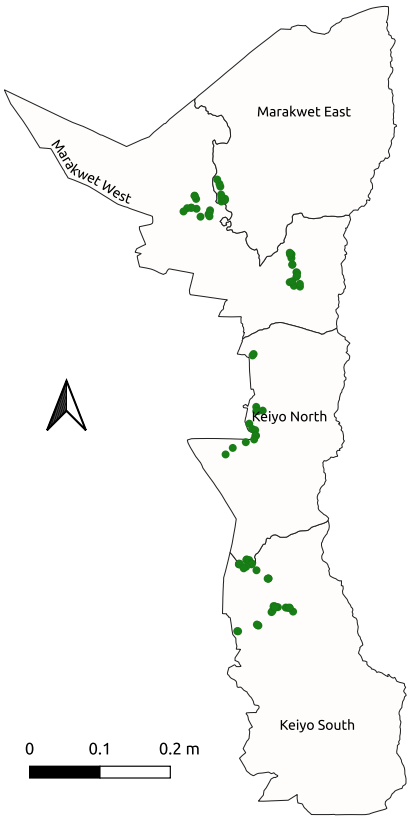


Figure 5.7: Sample collection locations in Elgeyo Marakwet county

Of the 91 farmers, 33% (30) were female and 67% (61), male (Figure 5.8). Most of the farmers were from Marakwet west (30, 33%) followed by Keiyo North (26, 29%), then Keiyo South (25, 27%) and lastly, Marakwet West (10, 11.0%). The age category of 46-55 years constituted the highest number but was not significantly differently from the 36-45- and $>$55-year categories both of which constituted 25%. The least categories were 31-35 years and $<$30-years which constituted 10 and 13% respectively (Figure 5.10 and Table 5.12). The majority of the farmers (63, 69.2%) grew potato as the first-choice crop followed by maize (20, 22%). Maize was also the top second-choice crop (Table 5.13). Of the farmers who selected potato as the fist choice crop, the majorly (60.3%, 38 of 63) grew it for income although about a third (36.5%, 23 of 63) grew the crop both for income and food. Only 2 farmers grew the crop solely for food (Table 5.14). The preferred potato variety was Shangi grown by 97.8% (89 of 91) of the farmers (Table 5.15).

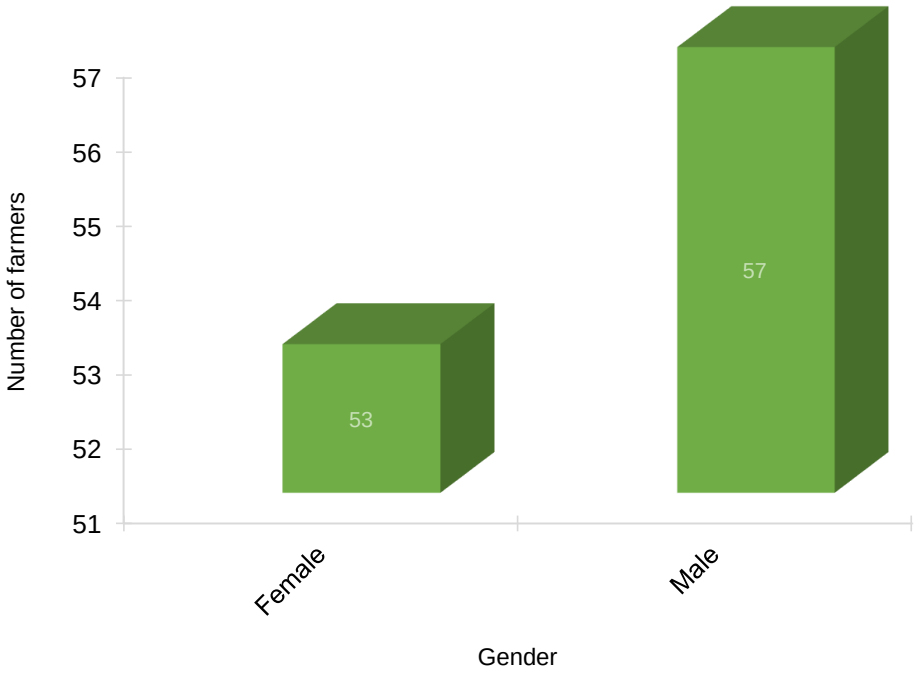


Figure 5.8: Proportion of female and male farmers interviewed in Elgeyo Marakwet county

Table 5.12: Number of interviewed farmers from Elgeyo Marakwet county disaggregated by gender, sub-county and ward

Sub-county	Farmers per ward		Total
	Female	Male	
Keiyo North			
Kamariny	4	3	7
Kapchemutwa	4	15	19
Keiyo South			
Kaptarakwa	11	14	25
Marakwet East			
Kapyego	4	6	10
Marakwet West			
Kapsowar	5	11	16
Lelan	2	12	14
Total	**30**	**61**	**91**

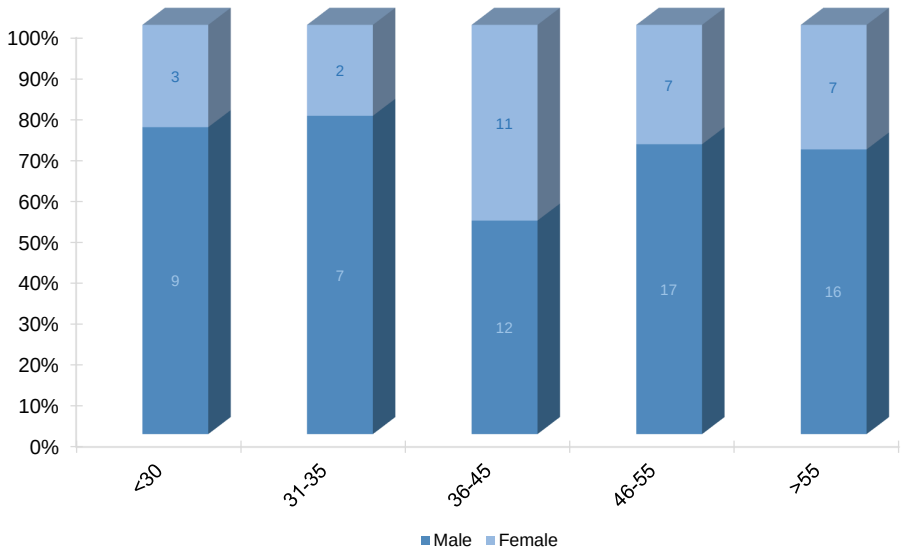


Figure 5.9: Disaggregation by age of all farmers interviewed in Elgeyo Marakwet county

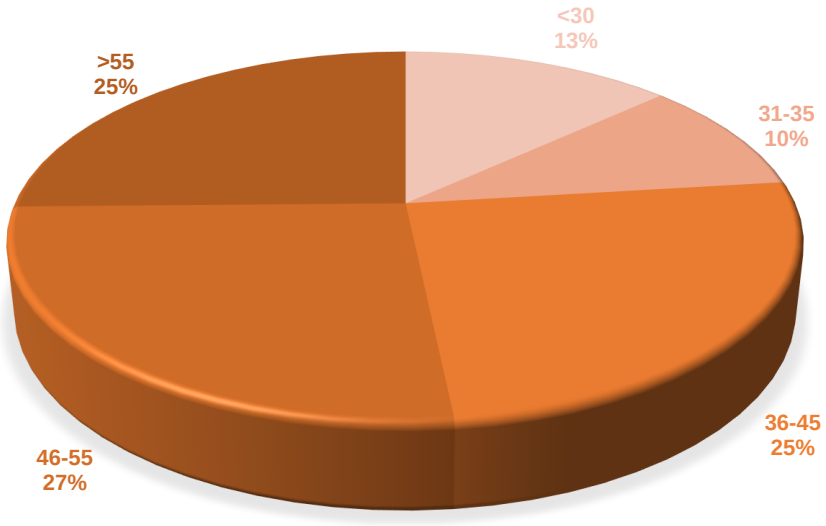


Figure 5.10: Proportion of the age categories of farmers interviewed in Elgeyo Marakwet county

Table 5.13: Crops grown in Elgeyo Marakwet county

Crop	Crop 1		Crop 2		Crop 3	
	Number	Acreage	Number	Acreage	Number	Acreage
Bananas					1	1.00
Beans	3	1.45	8	10.75	14	14.00
Boma Rhodes	1	1.50				
Butternut					1	1.00
Cabbages	1	0.50	8	2.74	10	10.00
Cowpeas			2	2.00	1	1.00
Garden peas	1	2.50	1	2.00	4	4.00
Kales					4	4.00
Maize	20	49.00	31	42.25	6	6.00
Napier grass			1	0.10	1	1.00
Oats					1	1.00
Onions			2	1.50	4	4.00
Passion fruit	1	0.60	1	0.25	1	1.00
Plums					1	1.00
Potatoes	63	103.15	20	15.80	6	6.00
Sweet potatoes					1	1.00
Tea			1	1.50		
Tomatoes	1	0.50			2	2.00
Tree Tomato			1	0.13		
Wheat			2	4.00		
None			13		33	
Total	**91**	**159.20**	**91**	**83.01**	**91**	**58.00**

Table 5.14: Use of crops indicated in Table 5.13

Crop	Crop 1				Crop 2				Crop 3		
	Food	Income	Both		Food	Income	Both		Food	Income	Both
Beans	2		1			2	6		3	4	7
Boma Rhodes		1									
Butternut										1	
Cabbages		1			2	2	4		3	3	4
Cowpeas						2				1	
Garden peas		1				1			2	1	1
Kales									2		2
Maize	2	2	16		20	2	9				
Napier grass					1						
Onions							2				
Passion fruit			1			1					
Plums											
Potatoes	2	38	23		3	6	11				
Tea						1					
Tomatoes			1								
Tree Tomato						1					
Wheat						1	1				
Total	**6**	**43**	**42**	**0**	**26**	**19**	**33**	**0**	**16**	**17**	**24**

Table 5.15: Potato varieties grown by farmers in Elgeyo Marakwet county

Potati variety	Choice		
	First	Second	Third
Dutch Robijn		1	
Konjo		1	
Shangi	89		
Tigoni	2	1	
Wanjiku			1
None		88	90
Total	**91**	**91**	**91**

Most of the farmers sourced potato planting materials from fellow farmers (72%) while 17.6% used own saved materials but only two (2%) farmers of the 91 purchased planting materials from local markets (Table 5.16). Very few farmers (6.6%) used certified seed from seed distributors. This demonstrates the over-reliance on the informal seed sector in this county. Most of the farmers selected more than one source of potato planting materials.

Table 5.16: Source of potato planting materials grown by farmers in Elgeyo Marakwet county

Sub-county	Source				
	Own-saved	Fellow farmers	Market	Seed distributors	Others
Keiyo North					
Kamariny	2	5			
Kapchemutwa	3	16			
Keiyo South					
Kaptarakwa	1	21		3	
Marakwet East					
Kapyego	4	6			1
Marakwet West					
Kapsowar		13	1	1	
Lelan	6	5	1	2	
Total	**16**	**66**	**2**	**6**	**1**

Most of the farmers did not use irrigation, certified seed and mulching (Figure 5.11). Mulching is not a very essential management practice in potato production however, certified seed is a key factor and the low usage is in line with the over-reliance on the informal seed sector as demonstrated in Table 5.16. The low usage of irrigation is known in this value chain. Irrigation was mostly reported by a few farmers around the Mt. Kenya region. Fertilizer application, pest management and weeding were used by more than 85% of farmers. Some of the pest management strategies apart from use of chemicals included scouting for pests (78, 85.7%), using recommended spacing (65, 71.4%) and crop rotation (61, 67%) (Figure 5.11). Maize is the crop most farmers used in rotations with potato (Table 5.17). However, maize may also host SRP especially *D. zeae* in the field.

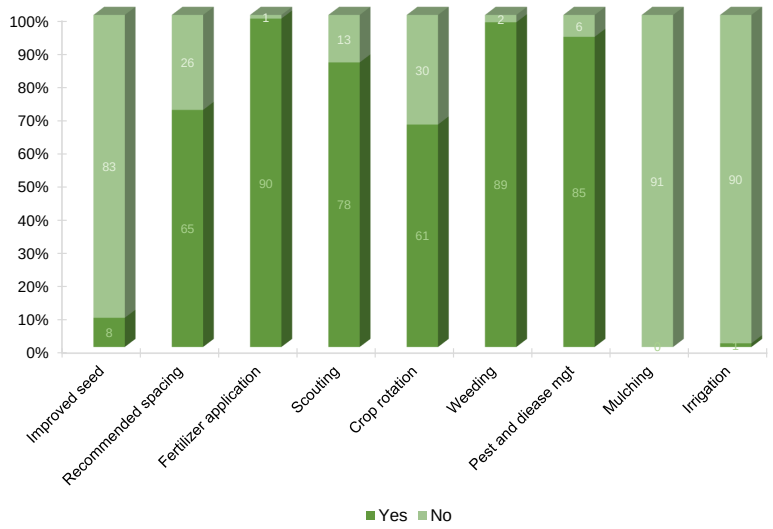


Figure 5.11: Agronomic practices implemented in potato production in Elgeyo Marakwet county

Table 5.17: Crops used in rotations in Elgeyo Marakwet county

Sub-county	Crop				
	Maize	**Cabbage**	**Wheat**	**Cowpeas**	**Passion fruits**
Keiyo North					
Kamariny	2	1		1	
Kapchemutwa	8			1	
Keiyo South					
Kaptarakwa	11	3			1
Marakwet East					
Kapyego	8				
Marakwet West					
Kapsowar	9	3	2		
Lelan	3				
Total	**41**	**7**	**2**	**2**	**1**
Propotion	**45.05**	**7.69**	**2.20**	**2.20**	**1.10**

Agronomic practices such as crop rotation, scouting for pests, weeding and other pest management strategies were used to mainly manage *A. solani*, *P. infestans* and *R. solanacearum*, whiteflies, aphids, and cutworms (Table 5.18 and 5.19). The SRP observed as blackleg was reported by only one farmer (Table 5.18) while there was no mention of bacterial ring rot.

Table 5.18: Pathogenic organisms managed by the agronomic practices indicated in Figure 5.11

Sub-county	Pathogenic organism					
	P. infestans	*R. solanacearum*	*A. solani*	Nematodes	Viruses	Blackleg
Keiyo North						
Kamariny	7	9	6		1	
Kapchemutwa	10		11	1		
Keiyo South				1		
Kaptarakwa	23	10	4			
Marakwet East				1		
Kapyego		4			1	
Marakwet West						
Kapsowar	13	10	3			1
Lelan	11	1		1		
Total	**64**	**34**	**24**	**4**	**2**	**1**
Proportion (%)	**70.33**	**37.36**	**26.37**	**4.40**	**2.20**	**1.10**

Table 5.19: Insects managed by the agronomic practices indicated in Figure 5.11

Sub-county	Pest						
	Whiteflies	Aphids	Cutworms	Tuber moth	Thrips	Spider mite	Millipedes
Keiyo North							
Kamariny	2	2	1				
Kapchemutwa	15	9	4	6	8	2	
Keiyo South							
Kaptarakwa	2	3	1	1			1
Marakwet East							
Kapyego			1				
Marakwet West							
Kapsowar	5	3	3	2			
Lelan	1		7				
Total	**25**	**17**	**17**	**9**	**8**	**2**	**1**
Proportion (%)	**27.47**	**18.68**	**18.68**	**9.89**	**8.79**	**2.20**	**1.10**

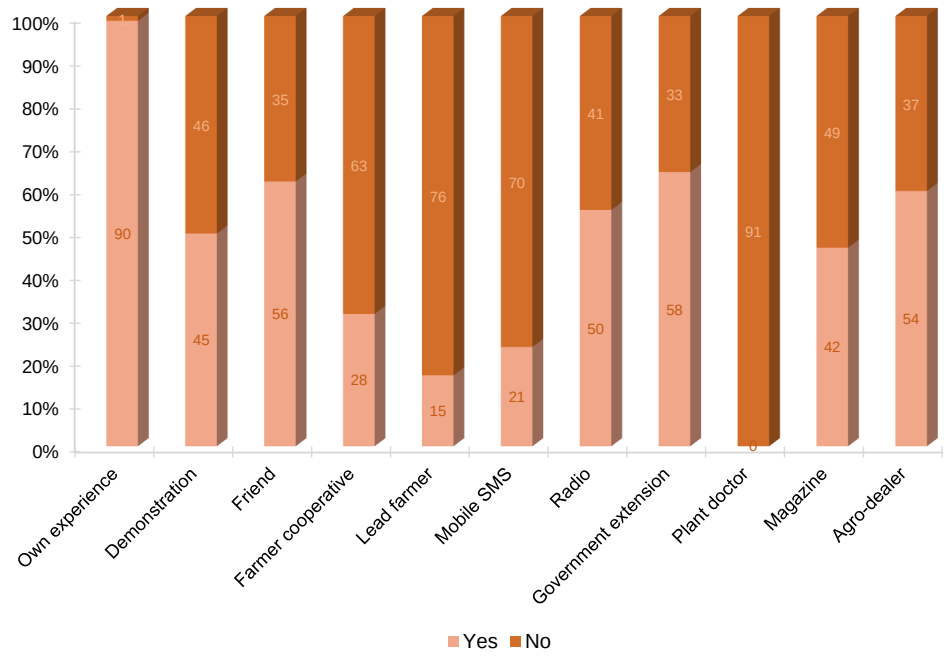


Figure 5.12: Sources of information for potato production and management of challenges in Elgeyo Marakwet county

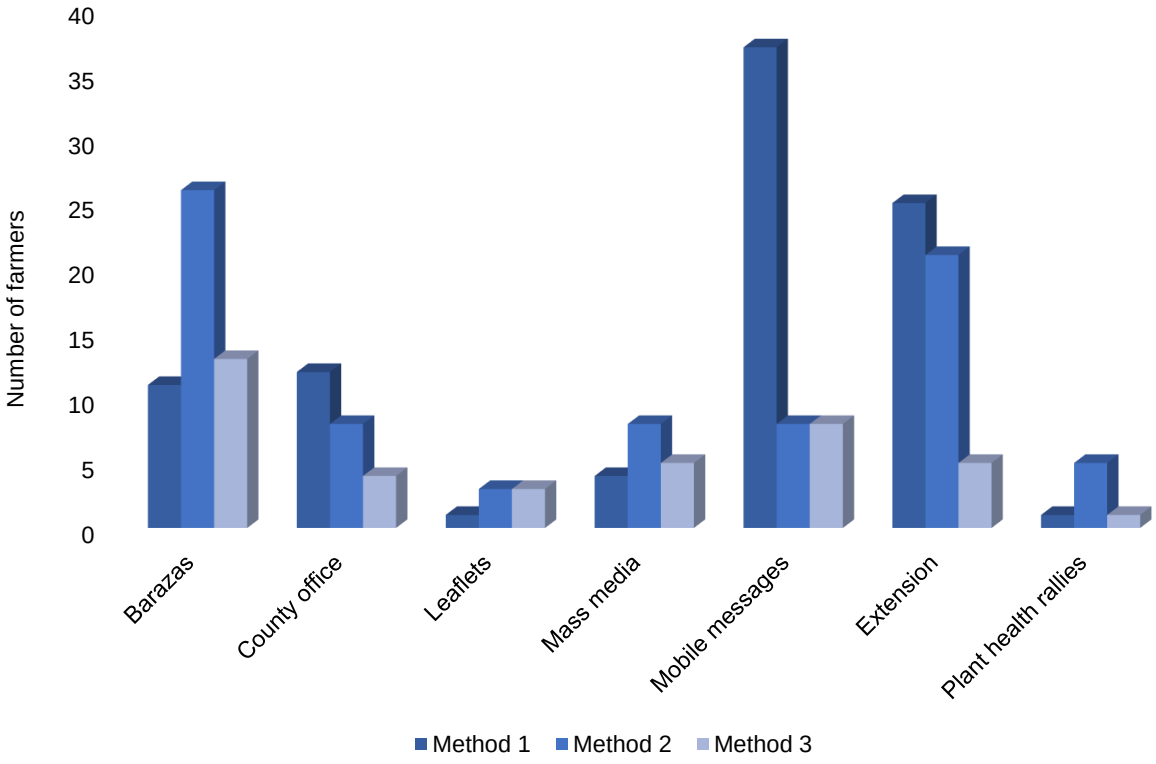


Figure 5.13: Method of choice for information dissemination in potato production in Elgeyo Marakwet county

Most of the farmers depended on own experience (selected by 99%) in potato production and management followed by friends (56, 61.5%), government extension (58, 63.7%); radio (50, 55.0%) and agro-dealer (54, 59.3%) which were selected in roughly equal proportions by the farmers with lead farmer and mobile SMS the least (Figure 5.12). Plant doctors did not future in Elgeyo Marakwet county because plant clinics are yet to be launched in this county. Of the 91 farmers, only 1 indicated to have observed bacterial ring rot (Table 5.10) while only 23 farmers observed SRP-associated diseases (Table 5.11. The observation of bacterial ring rot could have been confused with other symptoms but the low observations of SRP-associated diseases does not indicate absence of the pathogenic organism but probably a confusion of symptoms, lack of knowledge of the disease symptoms or presence of latent infections. In case of an outbreak of blackleg, soft rots and bacterial ring rot, the majority of farmers selected use of mobile messages followed by extension which was statistically similar to Barazas as their method of choice for information dissemination (Figure 5.13).

5.4 Meru County

A total of 122 farmers (12.2% of all farmers) from whom samples were also obtained were interviewed from Meru county. These farmers came from sub-counties and wards that were selected by the WAOs and forwarded to CABI by the CDA (Table 4.1). The farmers came from seven wards selected from three of the nine sub-counties, all of which were surveyed (Figure 5.14).

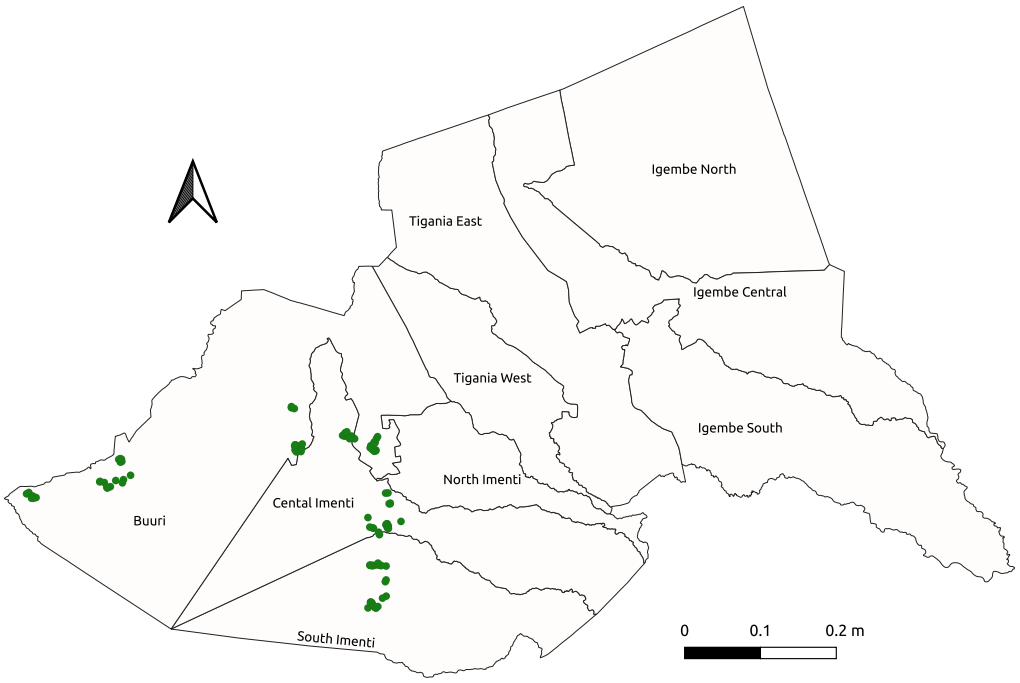


Figure 5.14: Sample collection locations in Meru county

Of the 122 farmers, 41% (50) were female and 59% (72), male (Figure 5.15 and Table 5.20). Most of the farmers were from Buuri (30, 33%) followed by Imenti South (26, 29%) and lastly, Central Imenti (10, 11%). The age categories of 46-55 and 36-45 years both constituted 30% of the total farmers interviewed followed by $>$55 years (26, 21%), then 31-35 years (20, 16%) and lastly $<$30 years (3, 3%) (Figures 5.16 and 5.17). The majority of farmers (105, 86%) grew potato as the first-choice crop. A number of crops were grown as second-choice with the list being topped by cabbage (43, 35.2%) and maize (41, 33.6%). Maize was the preferred third-choice crop followed by beans. Results available in Table 5.21. Farmers who grew potato as a first-choice crop, the majorly grew it for income (55, 45.1%). The second category which constituted 36.1% (44) grew the crop for both income and food. Only 6 farmers (about 5%) of the 122 grew potato solely for food. Results on usage of the crop available in Table 5.22. More than half of the farmers (64, 52.5%) sourced their seed from seed distributors (Table 5.24). The informal potato seed sector was very strong in Meru because the number of farmers who indicated using own saved planting materials closely matched those who accessed it from fellow farmers (45 vs 44 which constitutes approximately 36%)

with those who got it from the market constituting 8% (10). Another source of potato planting materials was free provision through the county government.

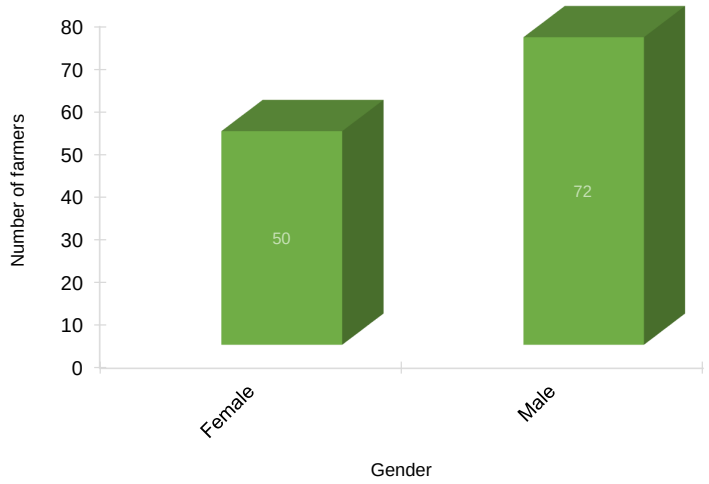


Figure 5.15: Proportion of female and male farmers interviewed in Meru county

Table 5.20: Number of interviewed farmers from Meru county disaggregated by gender, sub-county and ward

Sub-county	Farmers per ward		Total
	Female	Male	
Buuri			
Kibirichia	7	7	14
Kiirua/Naari	7	10	17
Kisima	6	13	19
Timau	11	11	22
Imenti Central			
Abothuguchi West	7	14	21
Imenti South			
Abogeta West	8	9	17
Nkuene	4	8	12
Total	**50**	**72**	**122**

The majority of the farmers used cultural practices such as recommended spacing (114, 93.4%), fertilizer application (122, 100%), scouting for pests (118, 96.7%), crop rotation (119, 97.5%) and weeding (115, 94.3%) (Figure 5.18). Mulching was not widely used and was only indicated by 1 farmer although this is not a key cultural practice in potato production. Irrigation has been widely reported to be used around Mt. Kenya region and is not a surprise that it was reported by 54% (66) of the farmers from Meru county. The high numbers (70.5%, 86) of farmers who reported using certified seed correlates well with results from source of planting materials where still more than half of the farmers sourced their seed from seed distributors (Figure 5.18, Table 5.24). All farmers indicated using pest management strategies.

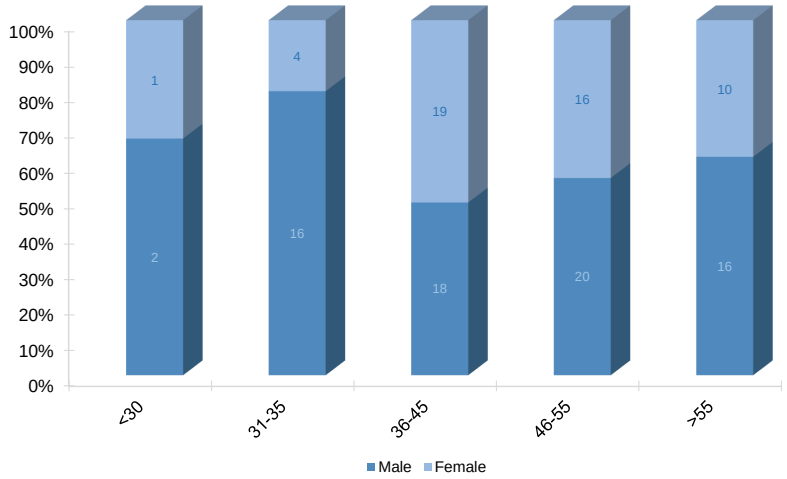


Figure 5.16: Disaggregation by age of all farmers interviewed in Meru county

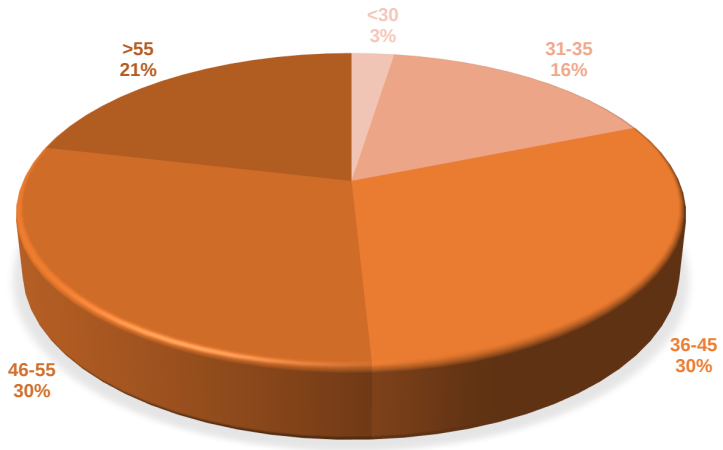


Figure 5.17: Proportion of the age categories of farmers interviewed in Meru county

Table 5.21: Crops grown in Meru county

Crop	Crop 1		Crop 2		Crop 3	
	Number	Acreage	Number	Acreage	Number	Acreage
Avocado					1	1.00
Beans			4	3.75	23	23.00
Cabbages	4	4.50	43	50.25	18	18.00
Carrots	1	0.25	7	3.25	8	8.00
Flowers	1	1.00			2	2.00
French beans	1	2.00	3	1.50	8	8.00
Garden peas			3	1.50	3	3.00
Maize	8	6.75	41	47.00	35	35.00
Onions			2	1.50		
Potatoes	105	149.75	13	9.25	4	4.00
Sweet potatoes	1	0.50				
Tea					1	1.00
Wheat	1	15.00	6	20.00	4	4.00
None					15	
Total	**122**	**179.75**	**122**	**138.00**	**122**	**107.00**

Table 5.22: Use of crops indicated in Table 5.21

Crop	Crop 1			Crop 2			Crop 3		
	Food	Income	Both	Food	Income	Both	Food	Income	Both
Avocado								1	
Beans						4	10	1	12
Cabbages		4			31	12	1	9	8
Carrots			1		5	2	1	4	3
Flowers		1						2	
French beans		1			3			8	
Garden peas					3			3	
Maize	3	1	4	12	3	26	27	3	5
Onions					2				
Potatoes	6	55	44	2	7	4		2	2
Sweet potatoes		1							
Tea								1	
Wheat			1			6		3	1
Total	**9**	**63**	**50**	**14**	**54**	**54**	**39**	**37**	**31**

Table 5.23: Potato varieties grown by farmers in Meru county

Potati variety	Choice		
	First	Second	Third
Asante	15	24	5
Challenger			1
Dutch Robijn	3	1	2
Jelly			1
Kaumbire	6	9	1
Shangi	87	13	
Sherekea	7	7	9
Umba	0	3	
Unica	2	2	
None	2	62	103
Total	**122**	**121**	**122**

Table 5.24: Source of potato planting materials grown by farmers in Meru county

Sub-county	Source				
	Own-saved	Fellow farmers	Market	Seed distributors	Others
Buuri					
Kibirichia	7	5		6	1
Kiirua/Naari	11	6		4	1
Kisima	10	4		8	
Timau	13	10	1	14	
Imenti Central					
Abothuguchi West	2	14	1	12	
Imenti South					
Abogeta West	1	2	4	13	
Nkuene	1	3	4	7	
Total	**45**	**44**	**10**	**64**	**2**

Some of the agronomic practices like crop rotation, scouting for pests and other pest management strategies were employed to manage pests including pathogenic organisms such as *A. solani*, *P. infestans*, *R. solanacearum* reported by 77% (94), 62% (76) and 65% (60) of the farmers respectively and insects such as thrips, aphids and cutworms reported by 25% (30), 20% (18) and 13% (12) of the farmers respectively (Tables 5.26 and 5.27).

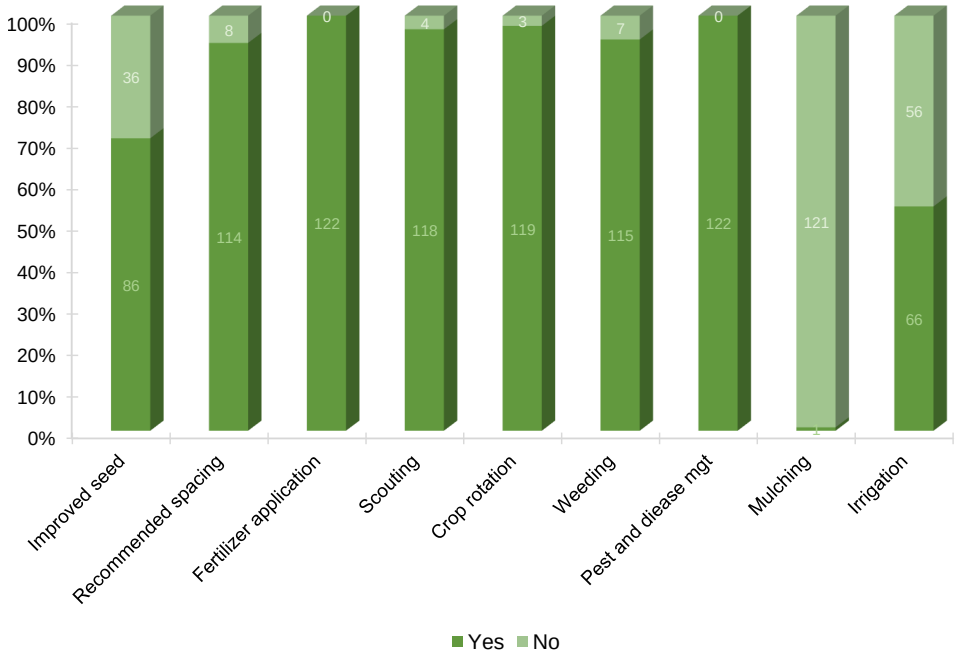


Figure 5.18: Agronomic practices implemented in potato production in Meru county

Table 5.25: Crops used in rotations in Meru county

Sub-county	Crop							
	Maize	**Cabbage**	**Beans**	**Carrots**	**French beans**	**Wheat**	**Garden peas**	**Onions**
Buuri								
Kibirichia	8	5	3	2		2	1	1
Kiirua/Naari	16	1	15	1				
Kisima	6	9	3	9	4	6	1	1
Timau	18	3	8	5		3	2	
Imenti Central								
Abothuguchi West	15	21	1		6			
Imenti South								
Abogeta West	15	17	2		2			
Nkuene	9	10			2		3	
Total	**87**	**66**	**32**	**17**	**14**	**11**	**7**	**2**
Propotion	**71.3**	**54.1**	**26.3**	**13.9**	**11.5**	**9.0**	**5.7**	**1.6**

Table 5.26: Pathogenic organisms managed by the agronomic practices indicated in Figure 5.18

Sub-county	Pathogenic organism						
	A. solani	*P. infestans*	*R. solanacearum*	Viruses	Nematodes	SRP-associated	Rust
Buuri							
Kibirichia	12	12	4		1		1
Kiirua/Naari	17	13	4	4			
Kisima	18	10	6	1			
Timau	17	17	15	3	1		
Imenti Central							
Abothuguchi West	14	9	14			1	
Imenti South							
Abogeta West	9	8	13				
Nkuene	7	7	4		1		
Total	**94**	**76**	**60**	**8**	**3**	**1**	**1**
Proportion (%)	**77.05**	**83.52**	**65.93**	**8.79**	**3.30**	**1.10**	**1.10**

Table 5.27: Insects managed by the agronomic practices indicated in Figure 5.18

Sub-county	Insect						
	Thrips	Aphids	Cutworms	Leafminers	Whiteflies	Spider mite	Tuber moth
Buuri							
Kibirichia	4						
Kiirua/Naari	2	1	2	2	1	1	
Kisima	6	6	1				1
Timau	3	2	2	1	3		
Imenti Central							
Abothuguchi West	7	6	2	5	4		1
Imenti South							
Abogeta West	4	1	1	1	1		
Nkuene	4	2	4			2	1
Total	**30**	**18**	**12**	**9**	**9**	**3**	**3**
Proportion (%)	**24.59**	**19.78**	**13.19**	**9.89**	**9.89**	**3.30**	**3.30**

Most the farmers depended on own experience (selected by 90%) in potato production and management. More than 45% indicated demonstration (45%, 55), friends (46%, 56) and government extension (48.4%, 59) as the preferred source of information (Figure 5.19). Mobile SMS and magazines were the least preferred. SRP-associated diseases were reported by 23 (18.9%) farmers which demonstrates either a lack of knowledge about the diseases, presence of latent infections or confusion of symptoms. In either case, some of the farmers uprooted blackleg-infected plants but did nothing for soft rot and some blackleg cases. Chemicals were used to manage the problem but is not an effective management strategy for diseases incited by bacteria (Table 5.11).

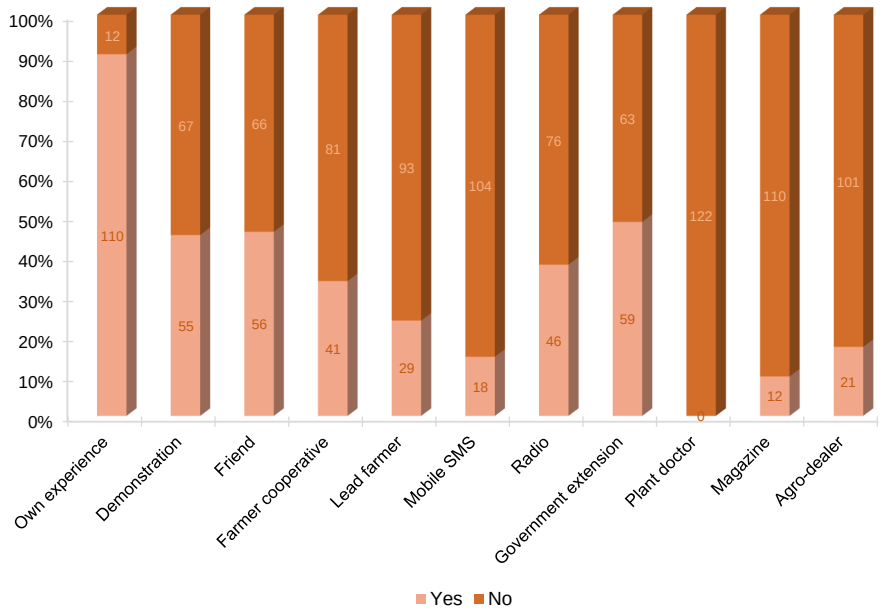


Figure 5.19: Sources of information for potato production and management of challenges in Meru county

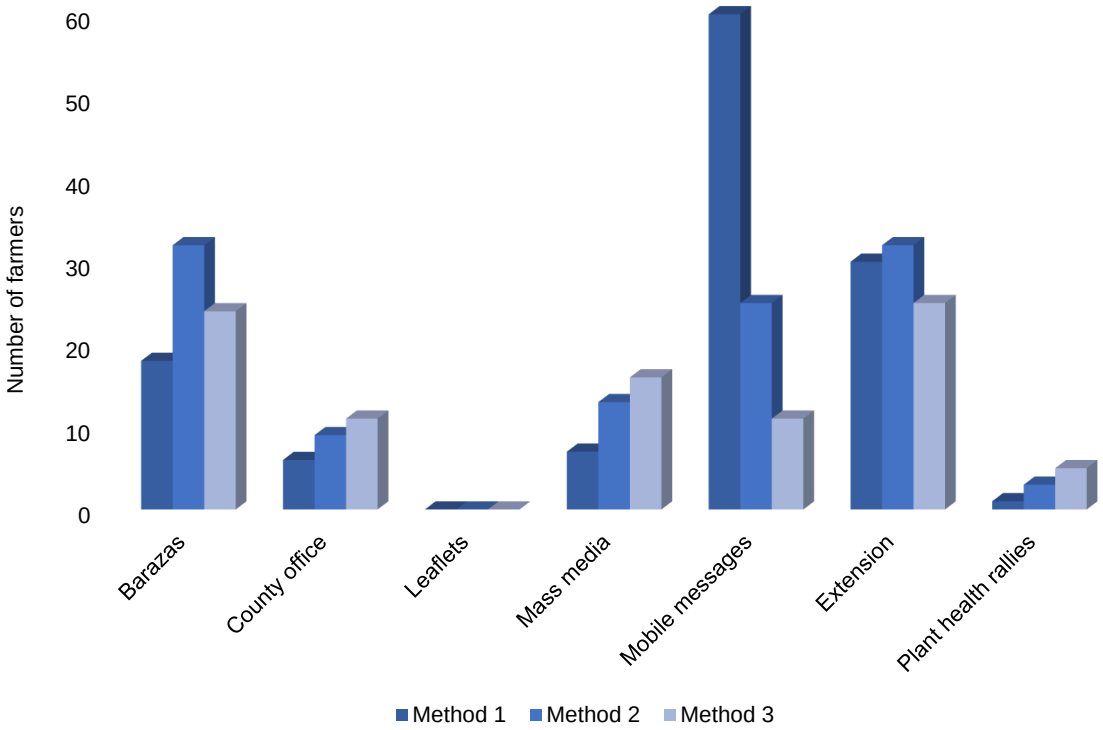


Figure 5.20: Method of choice for information dissemination in potato production in Meru county

Although Mobile SMS was not the main source of information, when farmers were asked the preferred method of choice for information dissemination in case of an outbreak of blackleg, soft rots and BRR, the majority preferred use of mobile messages followed by extension (Figure 5.20).

5.5 Nakuru County

A total of 268 farmers (26.7% of all farmers) from whom samples were also obtained were interviewed from Nakuru county. These farmers came from sub-counties and wards that were selected by the WAOs and forwarded to CABI by the CDA (Table 4.1). Nineteen wards from seven of the 11 sub-counties (Bahati, Gilgil, Kuresoi North, Kuresoi South, Molo, Naivasha, Njoro) were selected, thirteen of which were surveyed representing 68% of the selected wards (Figure 5.21 and Table 4.1). The 268 farmers comprised of 40.7% (109) female and 59.3% (159) male (Figure 5.22 and Table 5.28). Most of the farmers were from Kuresoi South (77, 28.7%), followed by Njoro (52, 19.4%), Molo (49, 18.3%) and Kuresoi North (46, 17.2%) with the least from Bahati (15, 5.6%), Gilgil (15, 5.5%) and Naivasha (14, 5.2%) (Table 5.28). The age category constituting the highest number of farmers was 36-45 years (77, 28%) followed by $>$55 years (66, 25%), 46-55 years (66, 24%) then 31-35 years (34, 13%) and lastly, $<$30 (26, 10%) ((Figures 5.23 and 5.24).). The majority (236, 88.1%) of the farmers were involved in potato production followed in a distant second (23, 8.6%) by maize which was also selected by 54.5% (146) of the farmers as their second-choice crop after potato (Table 5.29).

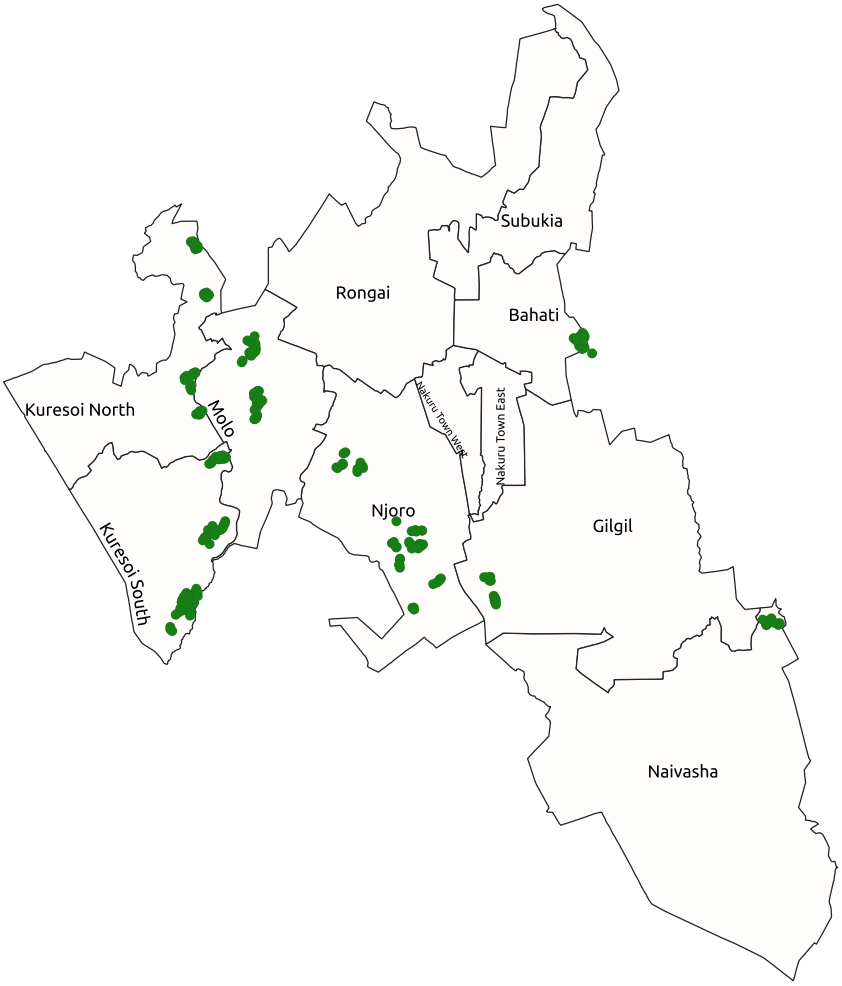


Figure 5.21: Sample collection locations in Nakuru county

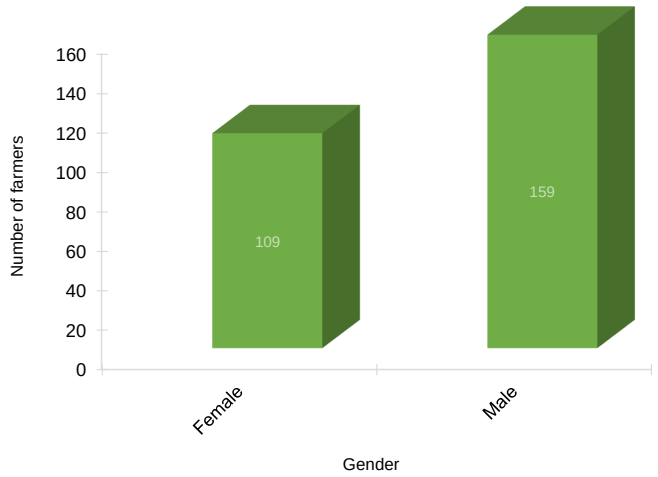


Figure 5.22: Proportion of female and male farmers interviewed in Nakuru county

Table 5.28: Number of interviewed farmers from Nakuru county disaggregated by gender, sub-county and ward

Sub-county	Farmers per ward		Total
	Female	Male	
Bahati			
Ndundori	6	9	15
Gilgil			
Elementaita	6	9	15
Kuresoi North			
Kamara	8	14	22
Nyota	2	8	10
Sirikwa	6	8	14
Kuresoi South			
Amalo	22	17	39
Keringet	18	20	38
Molo			
Elburgon	7	18	25
Molo	9	15	24
Naivasha			
Biashara	7	7	14
Njoro			
Mau Narok	7	13	20
Mauche	6	11	17
Nessuit	5	10	15
Total	**109**	**159**	**268**

The farmers who selected potato as the first-choice crop, 26.9% (72) grew it for income, 57.8% (155) grew it for both income and food while only 3.5% (9), grew it solely for food (Table 5.30). The majority of the farmers grew the variety Shangi (Table 5.31). The main source of potato planting materials for the interviewed farmers was own-saved materials which accounted for 63.4% (170). This was not significantly different from those who sourced it from fellow farmers (60.1%, 161) (Table 5.32). Only 13.4% (36) of the farmers reported accessing certified seed from seed distributors. Though very limited, some farmers mentioned buying seed from the market (2) while others (6) received from NGOs and the county government (Table 5.32). The agronomic practices employed included recommended spacing (260, 97%), fertilizer application (266, 99.3%), scouting for pests (238, 88.8%), crop rotation (212, 79.1%) and weeding (266, 99.3%). Mulching was not widely used and as indicated in earlier sections, it is not a practice very essential in potato production. Irrigation too was only reported by two farmers which is in line with what we expect as irrigation is not widely used by farmers especially those outside the Mt. Kenya region. Farmers were very keen on pest management as 98.1% (263) of the farmers conducted pest management.

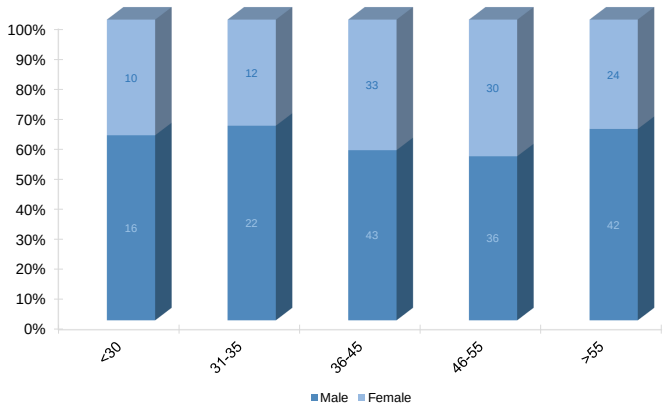


Figure 5.23: Disaggregation by age of all farmers interviewed in Nakuru county

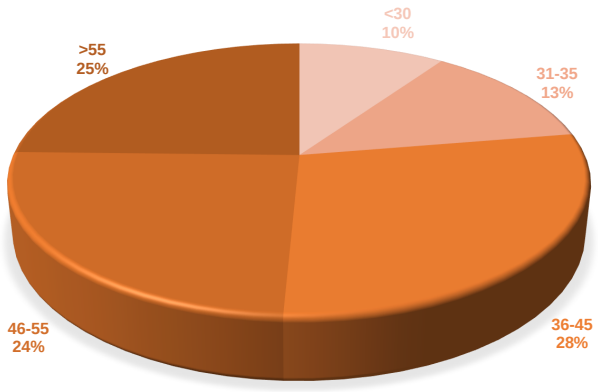


Figure 5.24: Proportion of the age categories of farmers interviewed in Nakuru county

Table 5.29: Crops grown in Nakuru county

Crop	Crop 1		Crop 2		Crop 3	
	Number	Acreage	Number	Acreage	Number	Acreage
Beans			10	6.75	44	44.00
Cabbages	4	2.25	24	43.75	28	28.00
Carrots	1	0.75	7	41.60	8	8.00
Garden peas	2	4.75	35	33.50	35	35.00
Groundnuts			1	0.50		
Kales					4	4.00
Maize	23	32.75	146	227.25	30	30.00
Oats			3	4.50	1	1.00
Onions					2	2.00
Pearl millet					1	1.00
Potatoes	236	449.75	26	22.25	4	4.00
Pyrethrum	1	2.00				
Sweet potatoes			1	1.50		
Tomatoes			1	0.25	1	1.00
Tree tomato					1	1.00
Wheat	1	4.00			1	1.00
None			14		108	
Total	**268**	**496.25**	**268**	**381.85**	**268**	**160.00**

Table 5.30: Use of crops indicated in Table 5.29

Crop	Crop 1			Crop 2			Crop 3		
	Food	Income	Both	Food	Income	Both	Food	Income	Both
Beans						10	10	3	31
Cabbages			4	2	13	9	3	8	17
Carrots		1		1	2	4		2	6
Garden peas		1	1	3	18	14	5	17	13
Groundnuts						1			
Kales							1	1	2
Maize	8	1	14	54	7	85	15	3	12
Oats				1		2		1	
Onions									2
Pearl millet									1
Potatoes	9	72	155	1	4	21	1		3
Pyrethrum		1							
Sweet potatoes						1			
Tomatoes						1		1	
Tree tomato									1
Wheat		1							1
Total	**17**	**77**	**174**	**62**	**44**	**148**	**35**	**36**	**89**

Table 5.31: Potato varieties grown by farmers in Nakuru county

Potato variety	Choice	
	First	Second
Dutch Robijn	4	5
Shangi	262	5
Sherekea		7
Stephen	2	5
Nderamwana		1
None		245
Total	**268**	**268**

Table 5.32: Source of potato planting materials grown by farmers in Nakuru county

Sub-county	Farmers interviewed				
	Own-saved	Fellow farmers	Market	Seed distributors	Others
Bahati	**13**	**1**	**1**		
Ndundori	13	1	1		
Gilgil					
Elementaita	11	9		1	2
Kuresoi North					
Kamara	7	13		1	1
Nyota	5	5			
Sirikwa	4	9		2	
Kuresoi South					
Amalo	22	26		6	
Keringet	17	24	1	9	
Molo					
Elburgon	14	11			3
Molo	21	19		2	
Naivasha					
Biashara	13	8			
Njoro					
Mau Narok	12	6		2	
Mauche	17	16		4	
Nessuit	14	14		9	
Total	**170**	**161**	**2**	**36**	**6**

Table 5.33: Crops used in rotations in Nakuru county

Sub-county	Crop											
	Maize	**Garden peas**	**Beans**	**Cabbage**	**Carrots**	**Kales**	**Wheat**	**French beans**	**Groundnuts**	**Tomatoes**	**Onions**	**Passion fruits**
Bahati												
Ndundori	7	4	4	11		1						
Gilgil												
Elementaita	12		10	2								
Kuresoi North												
Kamara	5	6		1								
Nyota	5	1		1	1	1					1	
Sirikwa	2	4		1					1			
Kuresoi South												
Amalo	34	9	9	10								
Keringet	30	19	1	7			1			1		1
Molo												
Elburgon	18			5	1							
Molo	22	2	10	5								
Naivasha												
Biashara	2	1		1	2							
Njoro												
Mau Narok	14	17		3	5			1				
Mauche	11	5	8									
Nessuit	15	3	8	1								
Total	**177**	**71**	**50**	**48**	**9**	**2**	**1**	**1**	**1**	**1**	**1**	**1**
Propotion	**66.0**	**26.5**	**18.7**	**17.9**	**3.4**	**0.8**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**	**0.4**

Maize, garden peas, beans and cabbage where the main crops used in rotations with potato which also explains why they also ranked high as second, or third-choice crops. Although at a very low frequency, one farmer from Kuresoi North rotated potato with tomatoes which is not advisable as both crops share same pests especially the first three indicated in Table 5.34.

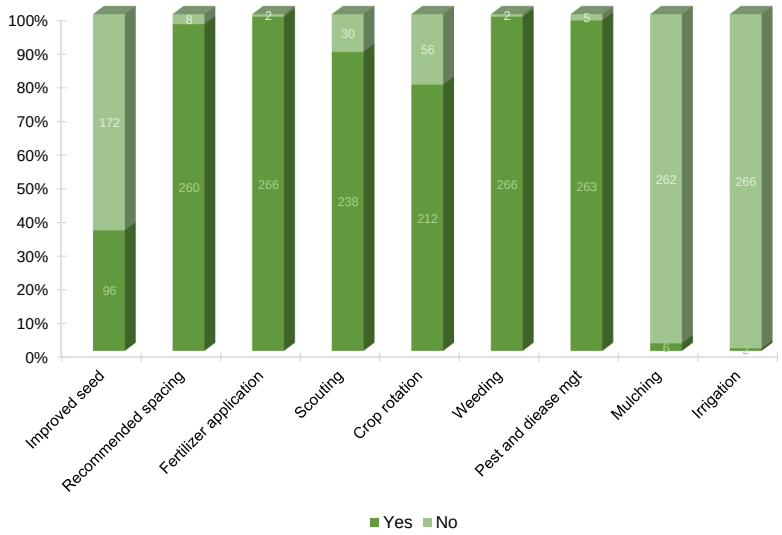


Figure 5.25: Agronomic practices implemented in potato production in Nakuru county

The pests managed by the various agronomic practices especially scouting for pests, crop rotation and other pest management strategies included *A. solani*, *P. infestans*, and *R. solanacearum*, cutworms, aphids and whiteflies (Table 5.34 and 5.35). SRP-associated diseases were mentioned by only seven farmers and no one mentioned bacterial ring rot. Most of the farmers used own experience in potato production and management. This is a trend that has been observed with other counties (Figure 5.26). This was followed in relatively equal frequencies by demonstration (148, 55.2%), friend (152, 56.7%), radio (165, 61.6%) and government extension (156, 58.2%). Plant doctors recorded the lowest frequency as a source of information partly because they are not yet widely distributed but also because they do not operate daily basis but at agreed intervals (like once a week or fortnight). Bacterial ring rot was not reported to have been observed by the farmers even after they were shown images depicting the disease and its symptoms (Figure 2.1). However, around 20 in every 100 farmers (54 of 268) did identify SRP-associated diseases (Table 5.11 and 5.36). The majority uprooted blackleg-infected plants but did nothing for soft rots which is understandable because soft rots manifest in tubers. Only one farmer reported the case to extension officers which is not ideal and a couple of them managed the problem with chemicals which is not an effective management strategy.

Table 5.34: Pathogenic organisms managed by the agronomic practices indicated in Figure 5.25

Sub-county	Pathogenic organisms				
	P. infestans	*A. solani*	*R. solanacearum*	SRP-associated	Viruses
Bahati					
Ndundori	15	15			
Gilgil					
Elementaita	15	9	6		
Kuresoi North					
Kamara	18	2	7		
Nyota	6	2			
Sirikwa	12	2	3		
Kuresoi South					
Amalo	37	38	29		
Keringet	38	38	12	1	
Molo					
Elburgon	21	12	6		1
Molo	22	22	21		
Naivasha					
Biashara	12	5	7		2
Njoro					
Mau Narok	20	20	1		
Mauche	17		15	4	
Nessuit	15		8	2	
Total	**248**	**165**	**115**	**7**	**3**
Proportion (%)	**92.5**	**61.6**	**42.9**	**2.6**	**1.1**

Table 5.35: Insects managed by the agronomic practices indicated in Figure 5.25

Sub-county	Insects					
	Cutworms	Aphids	Whiteflies	Tuber moth	Thrips	Spider mites
Bahati						
Ndundori	2	2				
Gilgil						
Elementaita	1					
Kuresoi North						
Kamara	7	4			1	
Nyota	3	1	1			
Sirikwa	3	4	1			
Kuresoi South						
Amalo						
Keringet	2		3	4		
Molo						
Elburgon	4	5	10	1	1	
Molo	1	1		4		1
Naivasha						
Biashara	1					
Njoro						
Mau Narok	2	3	3		1	
Mauche				1		
Nessuit		1	2	1		
Total	**26**	**21**	**20**	**11**	**3**	**1**
Proportion (%)	**21.31**	**17.21**	**16.39**	**9.02**	**2.46**	**0.82**

Table 5.36: Number of farmers who identified SRP-associated diseases in Nakuru and action taken

Sub-county	Observation		Total	Action			
	No	Yes		Reported to extension	Chemical	Uprooted	Did nothing
Bahati							
Ndundori	7	8	15			7	5
Gilgil							
Elementaita	12	3	15			3	2
Kuresoi North							
Kamara	22		22				
Nyota	7	3	10		2	1	
Sirikwa	12	2	14			2	
Kuresoi South							
Amalo	36	3	39			3	1
Keringet	28	10	38		2	3	5
Molo							
Elburgon	19	6	25		1	6	
Molo	21	3	24			2	1
Naivasha							
Biashara	12	2	14				2
Njoro							
Mau Narok	9	11	20	1	2	6	8
Mauche	14	3	17				3
Nessuit	15		15				
Total	**214**	**54**	**268**	**1**	**7**	**33**	**27**

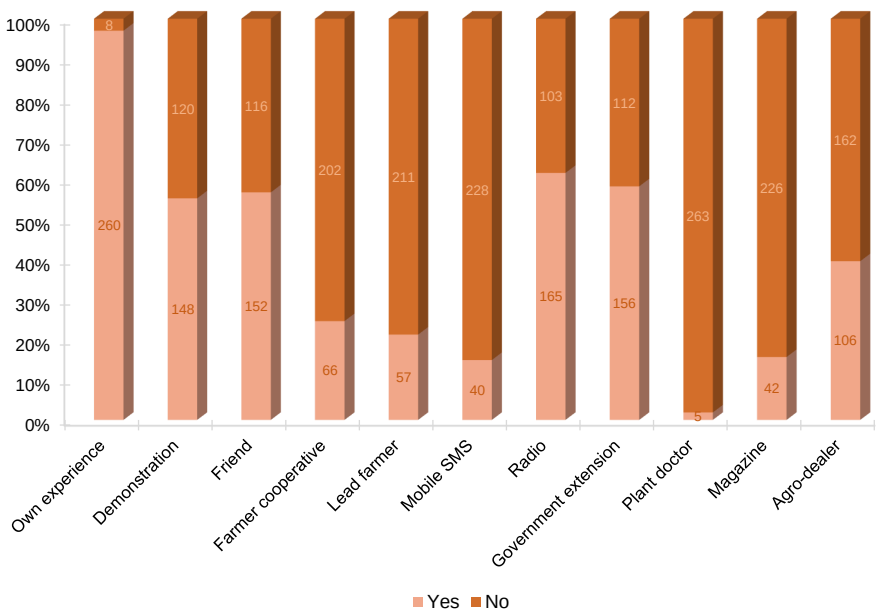


Figure 5.26: Sources of information for potato production and management of challenges in Nakuru county

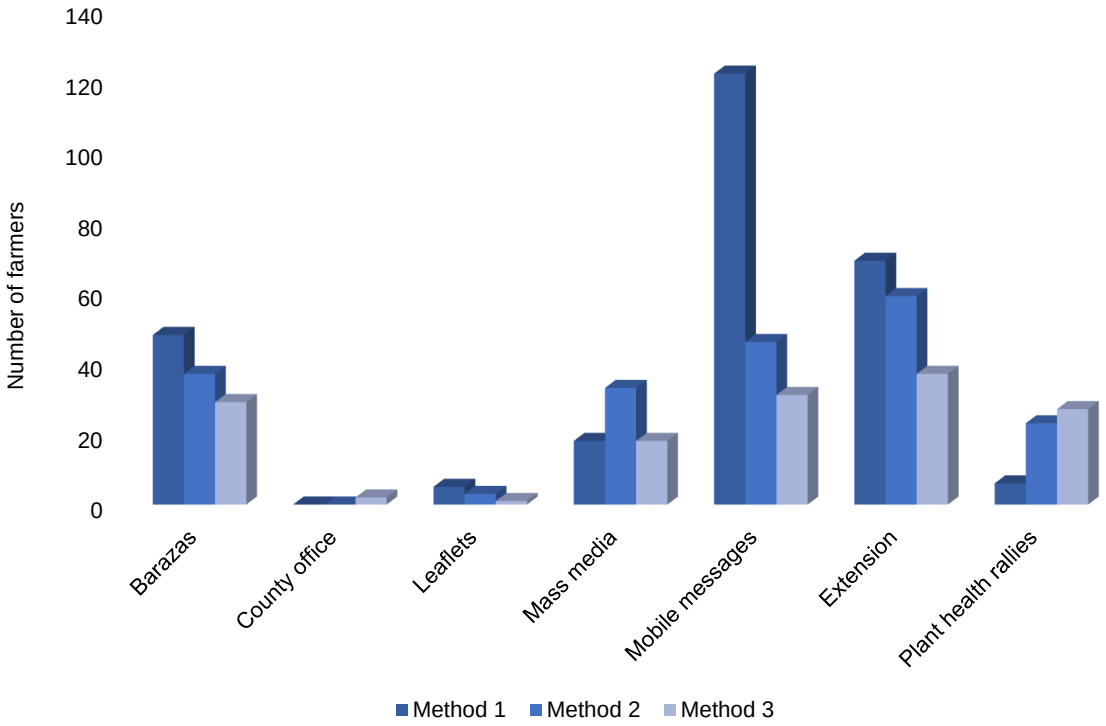


Figure 5.27: Method of choice for information dissemination in potato production in Nakuru county

When asked the method of choice for information dissemination in case of an outbreak of the blackleg, soft rots or ring rot, the majority selected mobile messaging followed by extension with Barazas coming in third (Figure 5.27).

5.6 Narok County

A total of 94 farmers (9.4% of all farmers) from whom samples were also obtained were interviewed from Narok county. These farmers came from sub-counties and wards that were selected by the WAOs and forwarded to CABI by the CDA (Table 4.1). Seven wards were selected from six sub-counties all of which were surveyed except for Olokurto (Figure 5.28 and Table 4.1).

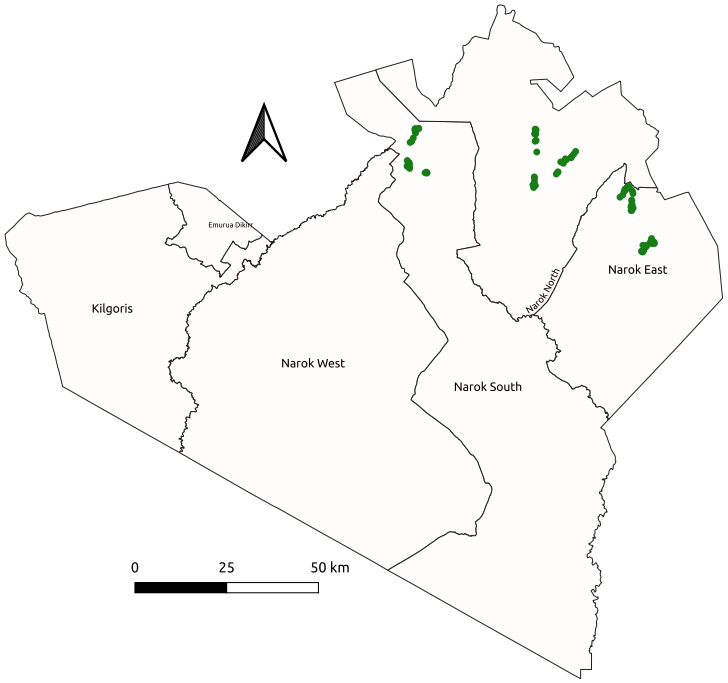


Figure 5.28: Sample collection locations in Narok county

Of the 94 farmers 34% (32%) were female and 66% (62), male (Figure 5.29 and Table 5.37). Most of the farmers were from Narok East (42, 44.7%), followed by Narok North (29, 30.9%) and lastly, Narok South (23, 24.5%). The age categories of 46-55 years constituted the highest number interviewees (42, 46%), followed by $>$55 years (20, 22%), then 36-45 (15, 16%), 31-35 years (11, 12%) and lastly $<$30 years (4, 4%) (Figures 5.30 and 5.31). The majority of farmers (84, 89.4%) grew potato as the first-choice crop. A number of crops were grown as second-choice with the list being topped by maize (52, 55.3%) and cabbages (14, 14.9%). Beans were the preferred third-choice crop followed by cabbages. Results available Table 5.38. Farmers who grew potato as a first-choice crop, the majority grew it for income (53, 56.4%) . The second category which constituted 47.3% (44) grew the crop for both income and food while only 1 farmer grew potato solely for food. Results on use of the crop is available in Table 5.39. Farmers in Narok grew a range of varieties (11 recorded in total) but like other counties, Shangi was the major variety grown reported by 78.7% (74) of the farmers as the first-choice (Figure 5.40). However, most of the seed for these varieties was sourced from fellow farmers (58, 61.7%), followed by using own saved planting materials (48, 51.1%) (Table 5.41). Some of the farmer (26, 27.7%) sourced their seed from distributors which correlates with use of improved seed reported by 62.8% (59) of the farmers (Figure 5.32). Farmers selected more than one source of planting materials.

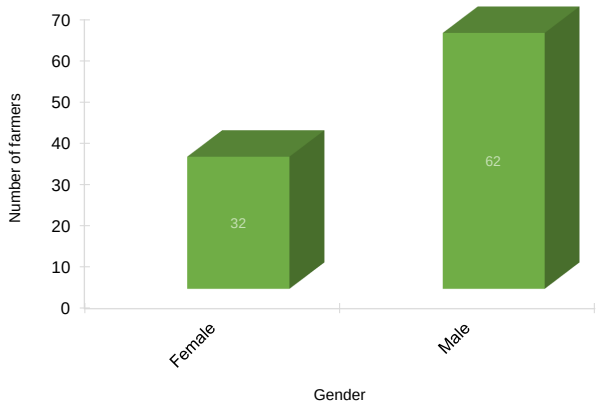


Figure 5.29: Proportion of female and male farmers interviewed in Narok county

Table 5.37: Number of interviewed farmers from Narok county disaggregated by gender, sub-county and ward

Sub-county	Farmers per ward		Total
	Female	Male	
Narok East			
Iidamat	10	11	21
Keekonyokie	7	14	21
Narok North			
Melili	1	12	13
Oloropil	6	10	16
Narok South			
Sagamian	5	6	11
Sogoo	3	9	12
Total	**32**	**62**	**94**

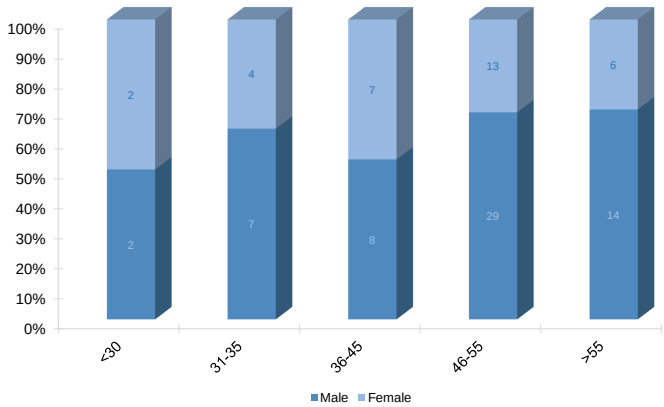


Figure 5.30: Disaggregation by age of all farmers interviewed in Narok county

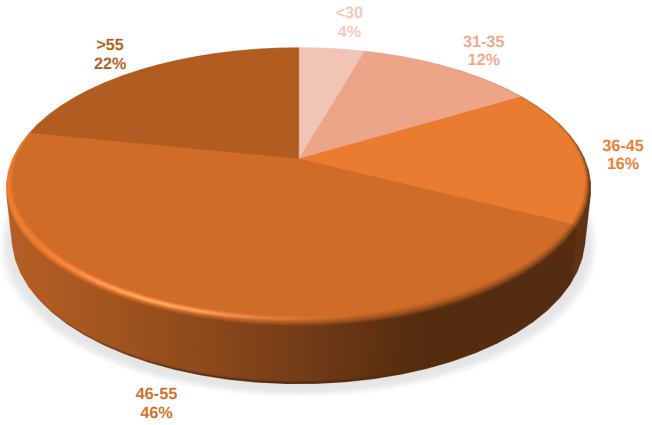


Figure 5.31: Proportion of the age categories of farmers interviewed in Narok county

Table 5.38: Crops grown in Narok county

Crop	Crop 1		Crop 2		Crop 3	
	Number	Acreage	Number	Acreage	Number	Acreage
Beans	1	5.00	7	17.50	29	29.00
Boma Rhodes					1	1.00
Cabbages			14	14.50	15	15.00
Carrots			1	1.00	8	8.00
Garden peas			4	3.25	4	4.00
Groundnuts					2	2.00
Kales			1	0.25	2	2.00
Maize	8	37.00	52	180.00	9	9.00
Potatoes	84	359.50	10	27.50		
Wheat	1	12.00	2	103.00	2	2.00
None			3		22	
Total	**94**	**413.50**	**94**	**347.00**	**94**	**72.00**

Table 5.39: Use of crops indicated in Table 5.38

Crop	Crop 1			Crop 2			Crop 3		
	Food	Income	Both	Food	Income	Both	Food	Income	Both
Beans			1		5	2	2	9	18
Boma Rhodes								1	
Cabbages				1	7	6	1	10	4
Carrots					1			3	5
Garden peas					1	3		3	1
Groundnuts								1	1
Kales				1				1	1
Maize		7	1	4	22	26		2	7
Potatoes	1	53	30		8	2			
Wheat		1			2			2	
Total	**1**	**61**	**32**	**6**	**46**	**39**	**3**	**32**	**37**

Table 5.40: Potato varieties grown by farmers in Narok county

Potato variety	Choice		
	First	Second	Third
Destiny	1	3	
Dutch Robijn	18	3	
Jelly		1	1
Manitou		1	1
Markies	1	3	1
Nyayo		1	
Panamera		2	1
Rudolph			1
Shangi	74	5	
Sherekea		2	
Voyager			3
None		73	86
Total	**94**	**94**	**94**

Table 5.41: Source of potato planting materials grown by farmers in Narok county

Sub-county	Source			
	Own saved	Fellow farmers	Market	Seed distributors
Narok East				
Iidamat	17	12		3
Keekonyokie	12	11	2	9
Narok North				
Melili	8	11		4
Oloropil	9	9		4
Narok South				
Sagamian		9	3	2
Sogoo	2	6		4
Total	**48**	**58**	**5**	**26**

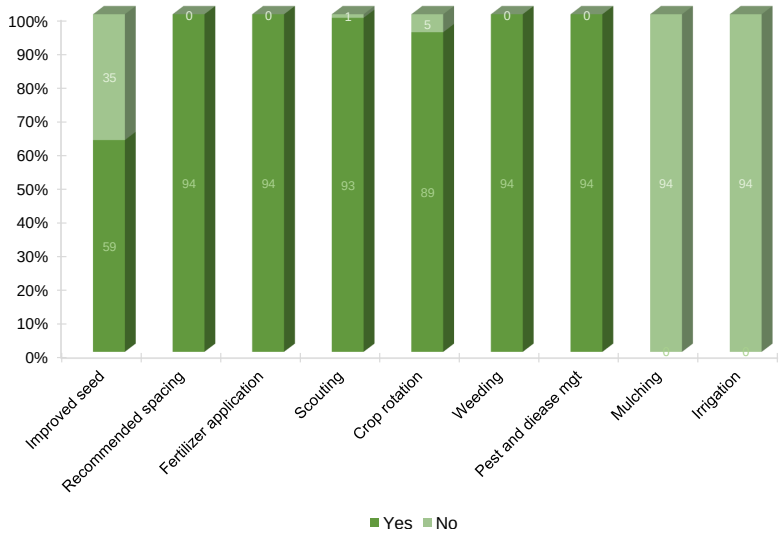


Figure 5.32: Agronomic practices implemented in potato production in Narok county

Table 5.42: Crops used in rotations in Narok county

Sub-county	Crop								
	Maize	**Beans**	**Cabbage**	**Garden peas**	**Carrots**	**Wheat**	**Kales**	**Tomatoes**	**Groundnuts**
Narok East									
Iidamat	18	1	14	5	8			1	1
Keekonyokie	16	13	3		1	2	1		
Narok North									
Melili	11	9	2	4		2			
Oloropil	12	5	6	2		1	1	1	
Narok South									
Sagamian	9	3	4						
Sogoo	9	9	4						
Total	**75**	**40**	**33**	**11**	**9**	**5**	**2**	**2**	**1**
Propotion	**79.8**	**42.6**	**35.1**	**11.7**	**9.6**	**5.3**	**2.1**	**2.3**	**1.1**

Table 5.43: Pathogenic organisms managed by the agronomic practices indicated in Figure 5.32

Sub-county	Pathogenic organism						
	P. infestans	*A. solani*	*R. solanacearum*	Nematodes	SRP-associated	Viruses	Rotting
Narok East							
Iidamat	20	19	3	2	1	1	
Keekonyokie	19	19	6	3	2		
Narok North							
Melili	13	13	4				
Oloropil	15	15	4	2	1		
Narok South							
Sagamian	5	5	5				1
Sogoo	11	7	6		1		
Total	**83**	**78**	**28**	**7**	**5**	**1**	**1**
Proportion (%)	**88.30**	**82.98**	**29.79**	**7.45**	**5.32**	**1.06**	**1.06**

Table 5.44: Insects managed by the agronomic practices indicated in Figure 5.32

Sub-county	Insect					
	Aphids	Tuber moth	White flies	Thrips	Spider mites	Cut worms
Narok East						
Iidamat	3		1			
Keekonyokie	1	2	1		1	
Narok North						
Melili	1		2	2		
Oloropil	2		5			1
Narok South						
Sagamian			4			
Sogoo			1			
Total	**7**	**2**	**14**	**2**	**1**	**1**
Proportion (%)	**7.45**	**2.13**	**14.89**	**2.13**	**1.06**	**1.06**

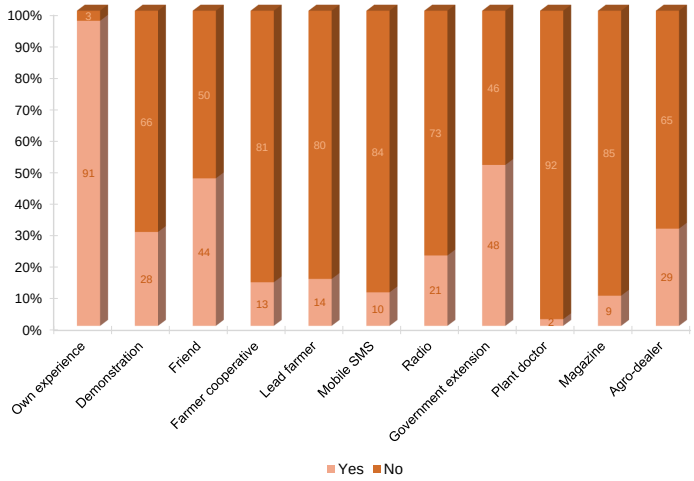


Figure 5.33: Sources of information for potato production and management of challenges in Narok county

All the farmers used recommended spacing, applied fertilizers, conducted weeding and managed pests with various pest management strategies however, 99% of the farmers conducted scouting for pests, 94.7% conducted rotations with other crops while improved seed was used by 62.7% of the farmers (Figure 5.32). None of the farmers used mulching which is not an essential agronomic practice in potato production and irrigation which has mainly been reported in the Mt. Kenya region. A number of crops were used in rotations with potato with maize, beans and cabbage being the top probably supporting why they were selected as second and third-choice crops as shown in Table 5.38. Although at a very low frequency, two farmers from Narok East and Narok North rotated potato with tomatoes which is not advisable as both crops share the same pests especially the top three indicated in Table 5.43. The pests managed by the various agronomic practices listed in Figure 5.32 included *A. solani* and *P. infestans*, and *R. solanacearum*. SRP-associated disease (Blackleg and soft rots) were mentioned by 5 farmers but there was no mention of bacterial ring rot. Whiteflies were the main insects mentioned by a couple of farmers although others such as tuber moth, aphids were mentioned by a couple of farmers (Table 5.44).

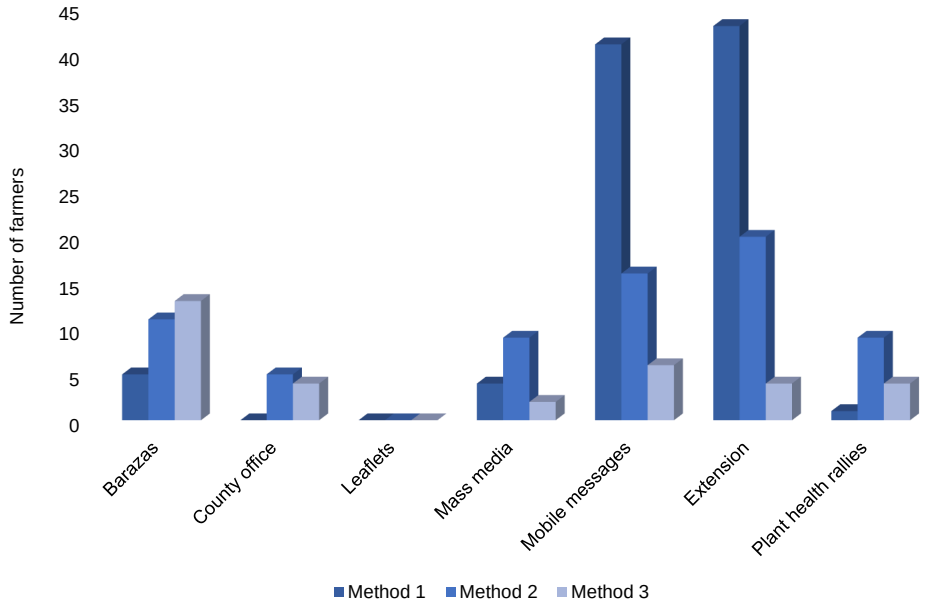


Figure 5.34: Method of choice for information dissemination in potato production in Narok county

Most (91, 96.8%) of the farmers used own experience in production and management of the challenges of the crop, a trend that has been observed with other counties (Figure 5.33). This was followed by government extension (48, 51.1%), friend (44, 46.8%), agro-dealer (29, 30.9% and demonstration (28, 29.8%. Plant doctors recorded the lowest frequency as a source of information partly because they are not yet widely distributed but also because they do not operate everyday but at agreed intervals (like once a week or fortnight). Bacterial ring rot was not reported to have been observed by the farmers even after they were shown images depicting the disease and its symptoms (Figure 5.9). However, around 19 in every 100 farmers (18 of 94) did identify SRP-associated diseases (blackleg and soft rots) (Table 5.11). The majority did nothing which is understandable especially for soft rots because they manifest in tubers. None reported the problems to extension officers which is not ideal and a couple addressed the problem especially for blackleg with chemicals which is not an effective management strategy for bacterial pests. When asked the method of choice for information dissemination in case of an outbreak of the blackleg, soft rots or ring rot, the majority selected extension followed by mobile messaging with Barazas coming in a distant third (Figure 5.34).

5.7 Nyandarua County

A total of 317 farmers (31.6% of all farmers) from whom samples were also obtained were interviewed from Nyandarua county. These farmers came from sub counties and wards that were selected by the WAOs and forwarded to CABI by the CDA (Table 4.1). All eighteen wards that where selected from all sub-counties (Kinangop, Kipipiri, Ndaragwa, Ol Joro Orok and Ol Kalou) were surveyed (Table 4.1, Figure 5.35). The 317 farmers comprised of 46.4% (147) female and 53.6% (170) male (Figure 5.36 and Table 5.45). Most of the farmers were from Kipipiri (84, 26.5%), followed by Ndaragwa (63, 19.9%), Ol Joro Orok (60, 18.9%) and Ol Kalou (59, 18.6%) and lastly Kinangop (51, 16%) (Table 5.45). The age category constituting the highest number of farmers was 46-55 years (92, 29%) followed by >55 years (90, 28%), 36-45 years (73, 23%) then 31-35 years (37, 12%) and lastly <30 (25, 8%) (Figures 5.37 and 5.38). A number of crops were selected by farmers but the majority (265, 83.6%) were involved in potato production followed in a distant second (33, 10.4%) by maize which was also selected by 44.5% (141) of the farmers as their second-choice crop after potato (Table 5.46). As a first-choice crop, potato also accounted for the biggest acreage followed by maize but came third after maize and french beans when selected as second-choice.

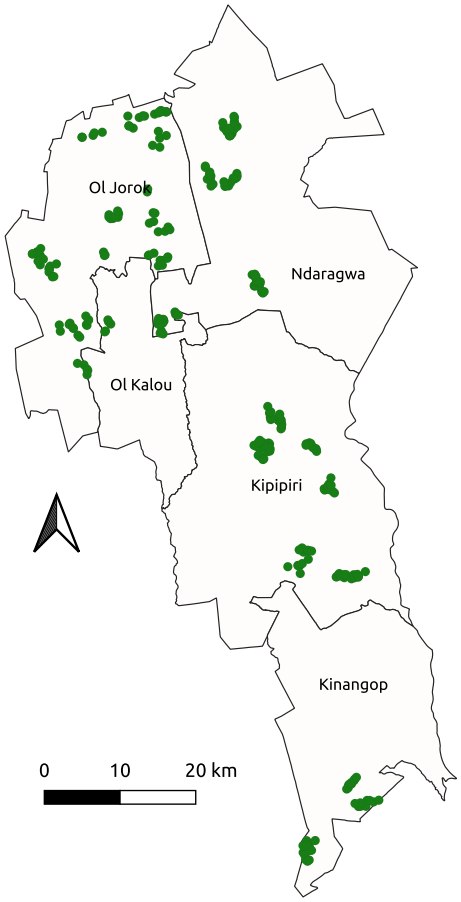


Figure 5.35: Sample collection locations in Nyandarua county

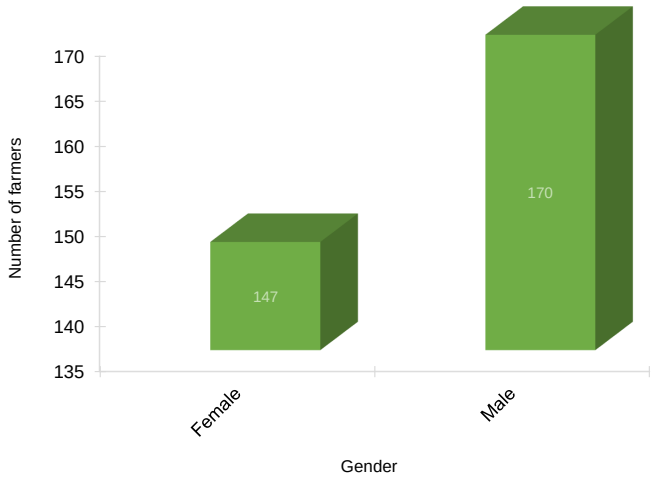


Figure 5.36: Proportion of female and male farmers interviewed in Nyandarua county

Table 5.45: Number of interviewed farmers from Nyandarua county disaggregated by gender, sub-county and ward

Sub-county	Farmers per ward		Total
	Female	Male	
Kinangop			
Magumu	9	1	10
Murungaru	2	11	13
North Kinangop	9	10	19
Nyakio	4	5	9
Kipipiri			
Geta	10	12	22
Kipipiri	9	13	22
Magumu	7	3	10
Nyakio	4	6	10
Wanjohi	13	7	20
Ndaragwa			
Central	9	13	22
Kiriita	11	9	20
Shamata	4	17	21
Ol Joro Orok			
Charagita	5	10	15
Gathanje	14	11	25
Weru	10	10	20
Ol Kalou			
Kanjuiri Ridge	12	9	21
Mirangine	7	14	21
Rurii	8	9	17
Total	**147**	**170**	**317**

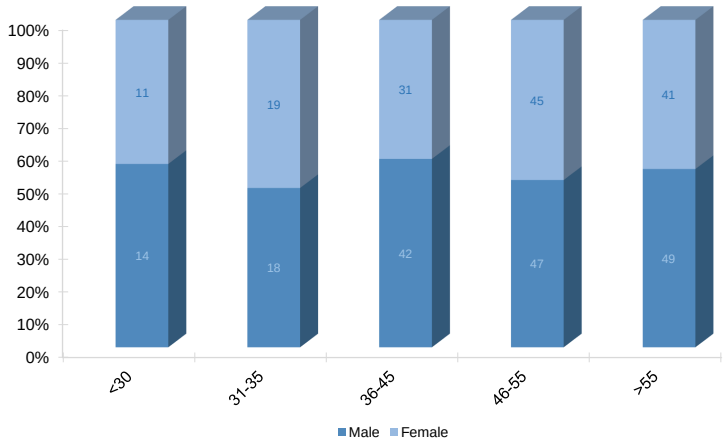


Figure 5.37: Disaggregation by age of all farmers interviewed in Nyandarua county

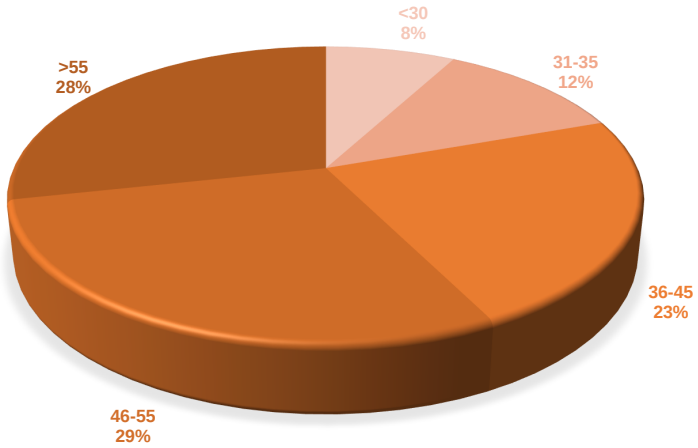


Figure 5.38: Proportion of the age categories of farmers interviewed in Nyandarua county

Whether selected as the first or second-choice crop, the majority (178, 56.2%) of farmers in either category indicated they grew potato to cater for both income and food followed by only income (73, 23%). Only about 4% (14) of the farmers grew the crop solely for food. In total, 11 varieties were grown with 4 selected as first-choice. Shangi was selected by the majority (314, 99.1%) with Destiny, Dutch Robijn and Tigoni each selected by one farmer (Table 5.48). Challenger, Dutch Robijn, Nderamwana, Panamera, Unica in addition to Shangi were selected as second-choice although there was also preference for Sherekea and Kenya Mpya as third-choice. The majority of farmers interviewed obtained their seed from informal sources. A proportion of 73.5% (233) used own saved planting materials (Table 5.49). This was followed by sourcing from fellow farmers (46.4%, 147) while a tiny fraction of about 2% (6) sourced from the market. Only about 9% (28) indicated obtaining seed distributors which correlated with information obtained about using improved seed in Figure 5.39. Others sources indicated by some of the farmers included the county government and NGOss.

Table 5.46: Crops grown in Nyandarua county

Crop	Crop 1		Crop 2		Crop 3	
	Number	Acreage	Number	Acreage	Number	Acreage
Beans	2	1.50	8	5.63	14	14.00
Beet root					1	1.00
Black nightshade			1	2.00		
Boma Rhodes	1	4.00				
Broccoli	1	0.25	1	1.00		
Cabbages	5	4.75	38	25.88	23	23.00
Carrots	3	1.75	18	11.13	34	34.00
French beans	1	0.50	2	1.00	1	1.00
Garden peas	3	2.25	29	31.73	43	43.00
Groundnuts			1	1.00		
Kales			4	1.00	5	5.00
Maize	33	44.00	141	145.16	25	25.00
Napier grass					1	1.00
Oats	1	1.00	1	1.50	2	2.00
Onions					2	2.00
Pigeon pea	1	2.00			1	1.00
Potatoes	265	445.09	38	26.75	9	9.00
Snow peas			4	4.25	2	2.00
Spinach					1	1.00
Sugarcane			1	0.50		
Tree Tomato			2	1.00	1	1.00
Wheat	1	5.00	1	2.50	4	4.00
None			27		148	
Total	**317**	**512.09**	**317**	**262.01**	**317**	**169.00**

Table 5.47: Use of crops indicated in Table 5.46

Crop	Crop 1			Crop 2			Crop 3		
	Food	Income	Both	Food	Income	Both	Food	Income	Both
Beans		1	1	2		6	11		3
Beet root								1	
Black nightshade						1			
Boma Rhodes			1						
Broccoli			1		1				
Cabbages		1	4	2	15	21	6	8	9
Carrots		2	1		11	7	2	10	22
French beans		1			2			1	
Garden peas		3		2	9	18	5	13	25
Groundnuts						1			
Kales				1		3	4		1
Maize	15	2	16	53	5	83	15	3	7
Napier grass								1	
Oats	1				1		1		1
Onions							2		
Pigeon pea			1					1	
Potatoes	14	73	178	10	6	22	3		6
Snow peas					4		2		
Spinach								1	
Sugarcane				1					
Tree Tomato					2				1
Wheat			1			1			4
Total	**30**	**83**	**204**	**71**	**56**	**163**	**51**	**39**	**79**

Table 5.48: Potato varieties grown by farmers in Nyandarua county

Potato variety	Choice		
	First	Second	Third
Challenger		1	
Destiny	1		
Dutch Robijn		8	1
Jelly	1		
Kenya Mpya			1
Nderamwana		1	
Panamera		2	
Shangi	314	2	
Sherekea			1
Tigoni	1		
Unica		3	
Unknown		1	
None		299	314
Total	**317**	**317**	**317**

Table 5.49: Source of potato planting materials grown by farmers in Nyaandarua county

Sub-county	Source				
	Own-saved	Fellow farmers	Market	Seed distributors	Others
Kinangop					
Magumu	7	2		2	
Murungaru	9	1		5	
North Kinangop	10	8		1	
Nyakio	9	9		2	
Kipipiri					
Geta	20	10		1	
Kipipiri	22	4	1	4	
Magumu	5	5	2	2	
Nyakio	3	4	1	2	
Wanjohi	18	4		1	
Ndaragwa					
Central	18	14		2	1
Kiriita	14	13	1		2
Shamata	19	12		1	
Ol Joro Orok					
Charagita	13	1		1	
Gathanje	6	15	1	3	2
Weru	7	12		1	
Ol Kalou					
Kanjuiri Ridge	20	14			
Mirangine	20	11			
Rurii	13	8			
Total	**233**	**147**	**6**	**28**	**5**

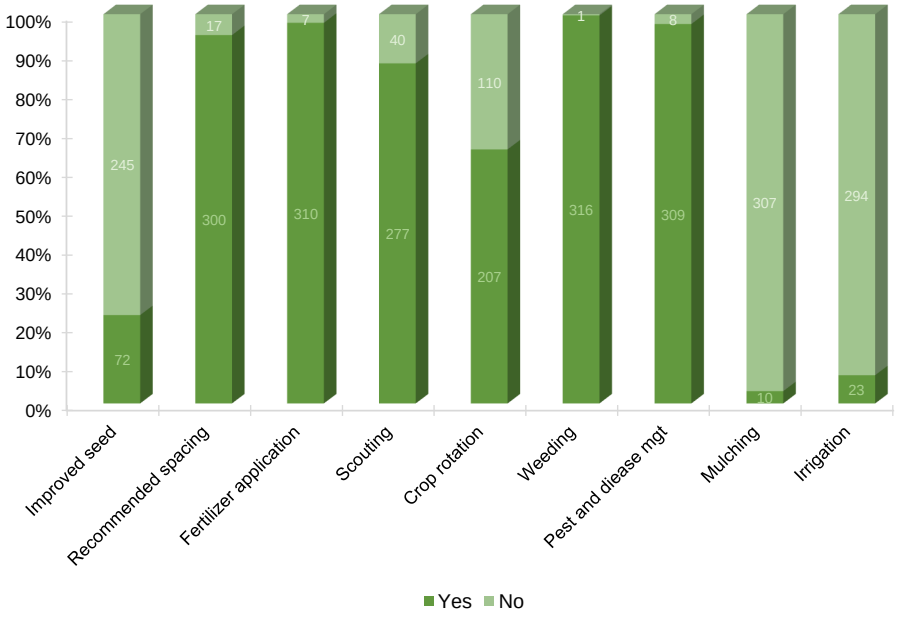


Figure 5.39: Agronomic practices implemented in potato production in Nyandarua county

The majority of farmers used key agronomic practices such as recommended spacing, fertilizer application, weeding in potato production and management (Figure 5.39). Mulching was not widely used and as indicated previously, it is not a key and essential practice in potato production. Irrigation too was reported by a few farmers (23, 7%) and as reported previously, it is not widely used in this value chain and only reported by a few farmers in the Mt. Kenya region. Use of improved seed was reported by less than a quarter (72, 22.7%) of farmers and the low usage is in line with the over-reliance on the informal seed sector as demonstrated in Table 5.49. Rotations with other crops were conducted by at least seven in ten of the farmers interviewed (207, 65%). Maize was the most rotated crop (129, 40.7%) followed by cabbage (67, 21.1%) while garden peas and carrots were mentioned in relatively equal proportions, 56 (17.7%) and 54 (17.0%) respectively (Table 5.50). Scouting for pests and use of other pest management strategies were reported by more than 70% of the farmers. Some of the pests managed and reported by more than quarter of the farmers included *A. solani*, *P. infestans*, and *R. solanacearum* (Table 5.51). Cutworms were the most observed insects and were indicated by at least one in ten farmers (Table 5.52). Most of the farmers depended on own experience (selected by 99%) in potato production and management (Figure 5.40). Radio came in second as the main source of information (221, 69.7%) followed by friend (178, 56.2%), government extension (152, 47.9%), demonstration (148, 46.7%) and agro-dealer (131, 41.3%). Mobile SMS were the least while plant doctors were not recorded. Plant doctors did not feature much because plant clinics are yet to be launched. Of the 317 farmers, only 1 indicated to have observed ring rot (Table 5.10) while 17% (55 of 317) observed SRP-associated diseases (blackleg and soft rots) (Table 5.11 and 5.53). The majority of farmers did nothing especially for soft rots while for blackleg, the plants were uprooted. None of the farmers reported the cases to extension and one used chemicals to manage blackleg.

Table 5.50: Crops used in rotations in Nyandarua county

Sub-county	Crop										
	Maize	**Cabbage**	**Garden peas**	**Carrots**	**Beans**	**Kales**	**French beans**	**Groundnuts**	**Wheat**	**Tomatoes**	**Passion fruits**
Kinangop											
Magumu	2	7	1	5		2					
Murungaru	1		1								
North Kinangop			2				2	3			
Nyakio	4	14		7		1					
Kipipiri											
Geta	7	6	13	13		1	2				
Kipipiri	20	6	11	8	1				1		
Magumu	4	8	2	6							
Wanjohi	8	7	3	12							
Ndaragwa											
Central	16	1	6		4						1
Kiriita	8	1	2		3	1				1	
Shamata	7	1	1								
Ol Joro Orok											
Charagita	3		1		1						
Gathanje	6	1									
Weru	5		3	1	1						
Ol Kalou											
Kanjuiri Ridge	11	3	2								
Mirangine	14	10	5	1							
Rurii	13	2	3	1	3	1					
Total	**129**	**67**	**56**	**54**	**13**	**6**	**4**	**3**	**1**	**1**	**1**
Propotion	**40.7**	**21.1**	**17.7**	**17.0**	**4.1**	**1.9**	**1.3**	**1.0**	**0.32**	**0.3**	**0.3**

Table 5.51: Pathogenic organisms managed by the agronomic practices indicated in Figure 5.39

Sub-county	Pathogenic organisms							
	P. infestans	*A. solani*	*R. solanacearum*	Viruses	Nematodes	SRP-associated	Rotting	*R. solani*
Kinangop								
Magumu	10	10	1		2		2	
Murungaru	10	2	1					
North Kinangop	15	2	3					1
Nyakio	19	10	6					
Kipipiri								
Geta	22	21	6		3	1		
Kipipiri	22	21	5			1		
Magumu	10	10						
Wanjohi	12	12	12		1	1	2	
Ndaragwa								
Central	22	11	9					
Kiriita	19	10	9	1				
Shamata	21	11	7		1	1		
Ol Joro Orok								
Charagita	9	2						
Gathanje	15		10					
Weru	16		6					
Ol Kalou								
Kanjuiri Ridge	21	9	10	7				
Mirangine	21	11	7	6		2		
Rurii	16	9	12	1	2	2		
Total	**280**	**151**	**104**	**15**	**9**	**8**	**4**	**1**
Proportion (%)	**88.33**	**47.63**	**32.81**	**4.73**	**2.84**	**2.52**	**1.26**	**0.32**

Table 5.52: Insects managed by the agronomic practices indicated in Figure 5.39

Sub-county	Insects										
	Cutworms	Whiteflies	Aphids	Millipedes	Tuber moth	Thrips	Spider mites	Army worm	Chafer grubs	Grasshoppers	Leaf miners
Kinangop		1									
Magumu					1						
Murungaru	1										
North Kinangop	2										
Nyakio	1		1		2		2				1
Kipipiri											
Geta						1					
Kipipiri	2	1	1								
Magumu			1								
Wanjohi		2				3					
Ndaragwa											
Central	3	1	1	1							
Kiriita							1				
Shamata	5								1		
Ol Joro Orok											
Charagita	3		1								
Gathanje	1	2	1	3				1		1	
Weru					1						
Ol Kalou											
Kanjuiri Ridge	4			1							
Mirangine	5			2							
Rurii	3	2	2		2						
Total	**30**	**9**	**8**	**7**	**6**	**4**	**3**	**1**	**1**	**1**	**1**
Proportion (%)	**9.46**	**2.84**	**2.52**	**2.21**	**1.89**	**1.26**	**0.95**	**0.32**	**0.32**	**0.32**	**0.32**

Table 5.53: Number of farmers who identified SRP-associated diseases in Nyandarua county and action taken

Sub-county	Observation		Total	Action			
	No	Yes		Report to extension	Chemical	Uprooted	Did nothing
Kinangop							
Magumu	9	1	10				1
Murungaru	13		13				
North Kinangop	19		19				
Nyakio	9		9				
Kipipiri							
Geta	16	6	22			3	4
Kipipiri	21	1	22		1		
Magumu	10		10				
Nyakio	7	3	10			3	2
Wanjohi	12	8	20	1	1	4	2
Ndaragwa							
Central	18	4	22			2	3
Kiriita	17	3	20				3
Shamata	19	2	21			1	1
Ol Joro Orok							
Charagita	15		15				
Gathanje	23	2	25		1	1	
Weru	20		20				
Ol Kalou							
Kanjuiri Ridge	15	6	21			2	5
Mirangine	12	9	21		1	2	8
Rurii	7	10	17			5	7
Total	**262**	**55**	**317**	1	4	23	36

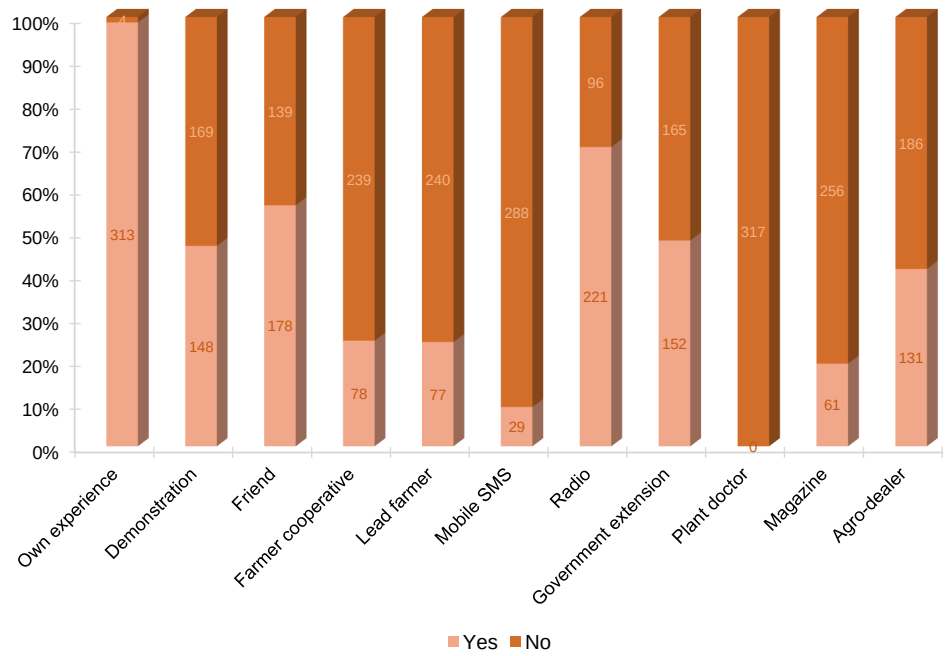


Figure 5.40: Sources of information for potato production and management of challenges in Nyandarua county

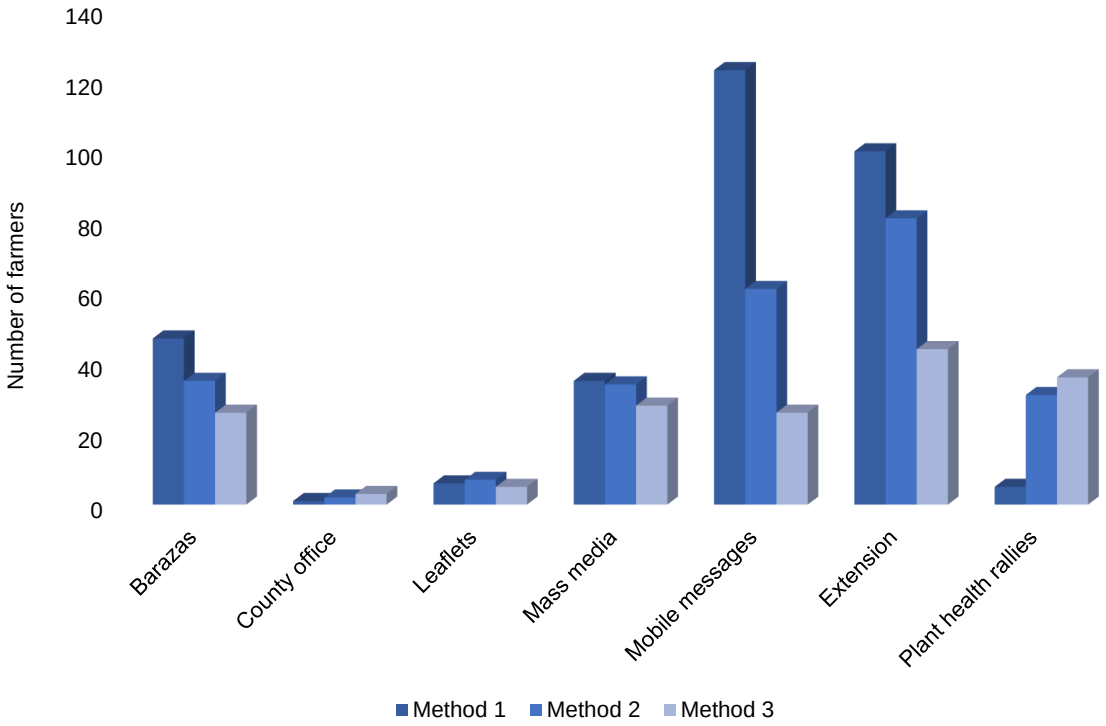


Figure 5.41: Method of choice for information dissemination in potato production in Nyandarua county

When asked which method of choice for information dissemination they preferred in case of an outbreak of blackleg, soft rots and bacterial ring rot, the majority of farmers selected use of mobile messages followed by extension and then Barazas (Figure 5.41).

5.8 Trans Nzoia County

A total of 110 farmers (11.0% of all farmers) from whom samples were also obtained were interviewed from Trans Nzoia county. These farmers came from sub-counties and wards that were selected by the WAOs and forwarded to CABI by the CDA (Table 4.1). All seven wards that where selected from all sub-counties (Cherangany, Endebess and Saboti) were surveyed (Table 4.1, Figure 5.42). The 110 farmers comprised of 48.0% (53) female and 52.0% (57) male (Figure 5.43 and Table 5.54). Most of the farmers were from Sabot (56, 50.9%), followed by Cherangany (28, 25.5%), and Endebess (26, 23.6%) (Table 5.54). The age category constituting the highest number was $>$55 years (29, 26.4%) followed by 46-55 years (28, 25.5%), then 36-45 years, (24, 21.8%), 31-35 years (16, 14.6%) and lastly $<$30 years (13, 11.8%).

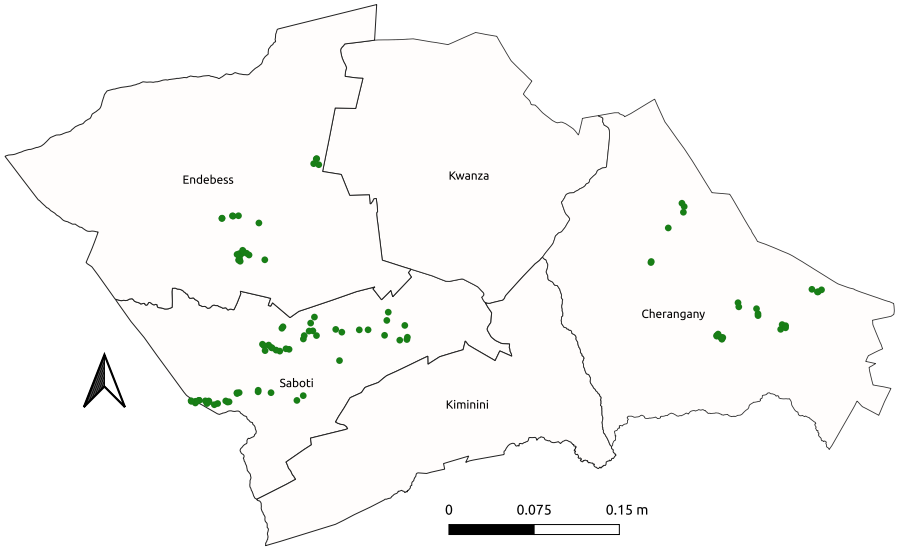


Figure 5.42: Sample collection locations in Trans Nzoia county.

Up to 22 crops were grown as the first, second- or third-choice crops, however, the majority (77, 70%) grew potato as their first-choice while 12 (10.9%) grew the crop as the second- and third-choice crop (Table 5.55). Potato also accounted for the highest acreage as the first-choice crop. Bananas were selected as the second-choice crop followed by maize, a trend that was observed for the third-choice crop as well (Table 5.55). The majority (39, 35.5%) of the farmers grew potato for income, 23.6% (26) grew the crop for both income and food while 10.9% (12) grew the crop solely fro food. The farmers mentioned up to 11 varieties that were grown with Shangi being the most widely grown as indicated by 66.4% (73) of the farmers (Table 5.57). This was a trend observed in all other counties. Interestingly Kabale is a Ugandan variety and was the second most grown in Trans Nzoia. Most of the farmers (64, 58.2%) sourced planting materials from fellow farmers (Table 5.58). This was followed by sourcing from the market (26, 23.6%) with the least being using own planting materials (9, 8.2%). However, 10.9% (12) of the farmers sourced their planting materials from seed distributors which correlates with figures of farmers who indicated that they used improved seed (Figure 5.46). Note; most of the farmers selected multiple sources of planting materials.

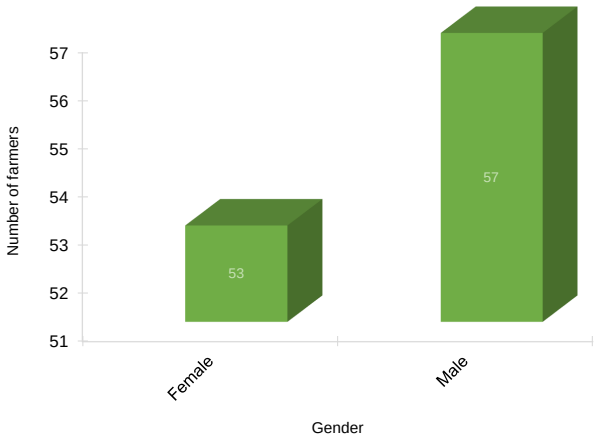


Figure 5.43: Proportion of female and male farmers interviewed in Trans Nzoia county

Table 5.54: Number of interviewed farmers from Trans Nzoia county disaggregated by gender, sub-county and ward

Sub-county	Farmers per ward		Total
	Female	Male	
Cherangany			
Cherangani/Suwerwa	11	11	22
Makutano	4	2	6
Endebess			
Chepchoina	3	2	5
Endebess	7	7	14
Matumbei	3	4	7
Saboti			
Kinyoro	17	14	31
Saboti	8	17	25
Total	**53**	**57**	**110**

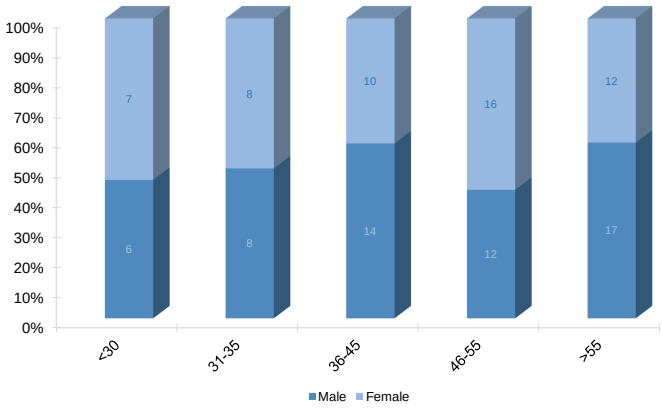


Figure 5.44: Disaggregation by age of all farmers interviewed in Trans Nzoia county

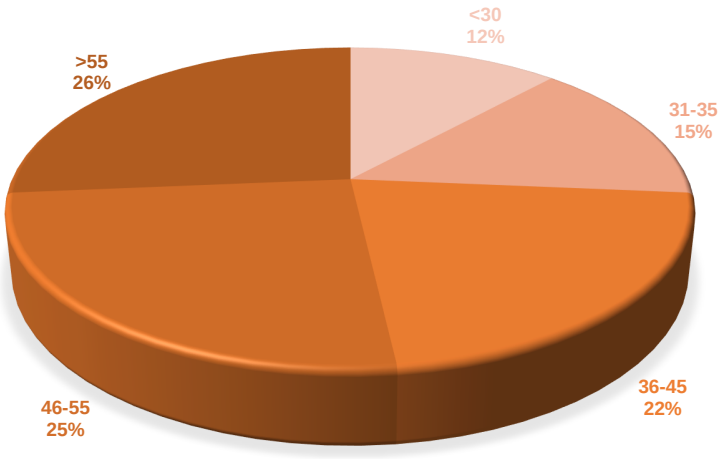


Figure 5.45: Proportion of the age categories of farmers interviewed in Trans Nzoia county

Table 5.55: Crops grown in Trans Nzoia county

Crop	Crop 1		Crop 2		Crop 3	
	Number	Acreage	Number	Acreage	Number	Acreage
Bananas					1	1.00
Beans	5	8.00	27	55.40	18	18.00
Beet root					1	1.00
Cabbages	1	0.25	5	2.80	6	6.00
Capsicum			1	1.00		
Coffee			1	0.25		
Cowpeas			2	0.50		
French beans			1	1.00	1	1.00
Kales	4	2.10	4	1.30	3	3.00
Maize	20	407.50	26	55.60	12	12.00
Millet					1	1.00
Onions			2	3.06		
Pearl millet	1	0.25	1	0.25		
Potatoes	77	50.53	12	3.81	12	12.00
Snow peas			1	1.50	1	1.00
Sorghum	1	0.50	1	20.00		
Spider plant			1	0.13		
Sugarcane			1	0.50		
Sweet potatoes			1	0.25		
Tea	1	0.80				
Tomatoes			6	5.45	5	5.00
Wheat			2	70.13		
None			15		49	
Total	**110**	**469.93**	**110**	**222.92**	**110**	**61.0**

Table 5.56: Usage of crops indicated in Table 5.55

Crop	Crop 1			Crop 2			Crop 3		
	Food	Income	Both	Food	Income	Both	Food	Income	Both
Bananas							1		
Beans	1		4	6	5	16	5	5	8
Beet root								1	
Cabbages		1			4	1	2	3	1
Capsicum					1				
Coffee					1				
Cowpeas					2				
French beans					1				1
Kales			4		1	3	1	1	1
Maize	5	2	13	4	11	11	3	2	7
Millet									1
Onions				1	1				
Pearl millet			1		1				
Potatoes	12	39	26	5	1	6	2	1	9
Snow peas					1			1	
Sorghum			1			1			
Spider plant				1					
Sugarcane					1				
Sweet potatoes				1					
Tea			1						
Tomatoes					5	1		2	3
Wheat				1	1				
Total	**18**	**42**	**50**	**19**	**37**	**39**	**14**	**16**	**31**

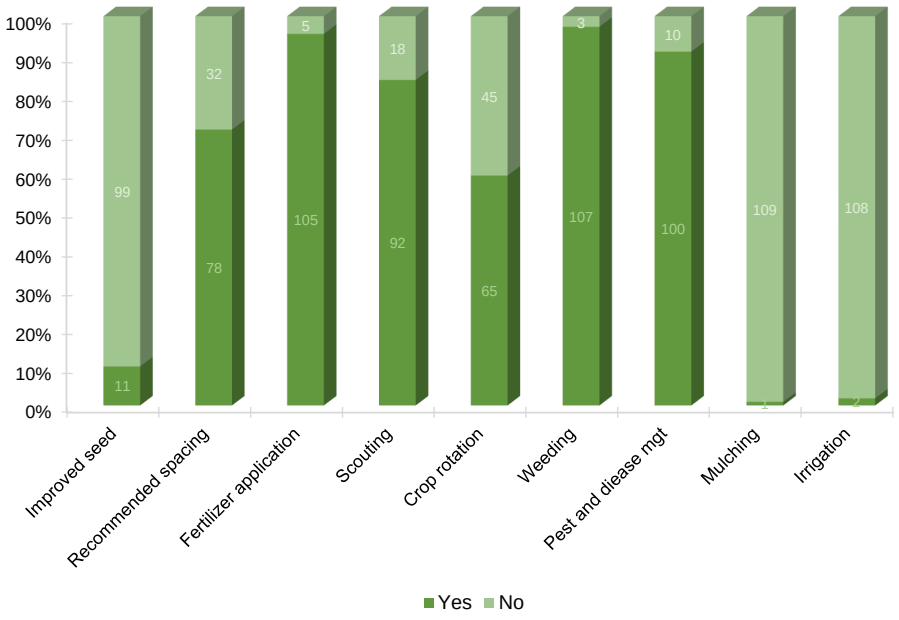


Figure 5.46: Agronomic practices implemented in potato production in Trans Nzoia county

Table 5.57: Potato varieties grown by farmers in Trans Nzoia county

Potato variety	Choice		
	First	Second	Third
Arka	3	1	
Asante	1		
Dutch Robijn	8		
Kabale	10	6	
Kenya Mpya	1	1	1
Lenana		1	
Purple Gold	1	1	
Shangi	73	4	
Sherekea	3		1
Tigoni	8	1	
Unica	1	1	
Unknown	1		
None		94	108
Total	**110**	**110**	**110**

Table 5.58: Source of potato planting materials grown by farmers in Trans Nzoia county

Sub-county	Source			
	Own-saved	Fellow farmers	Market	Seed distributors
Cherangany				
Cherangani/Suwerwa	1	11	2	8
Makutano	2	3	1	
Endebess				
Chepchoina		1	4	
Endebess	1	10	2	1
Matumbei		6	1	
Saboti				
Kinyoro	2	20	7	2
Saboti	3	13	9	1
Total	**9**	**64**	**26**	**12**

Table 5.59: Crops used in rotations in Trans Nzoia county

county	Crop						
	Maize	**Beans**	**Cabbage**	**Kales**	**Garden peas**	**Tomatoes**	**Cowpeas**
Cherangany							
Cherangani/Suwerwa	5	5	3		2		1
Makutano	2		1	1			
Endebess							
Chepchoina	2	3		1			
Endebess	5	2	1				
Matumbei	4	3				1	
Saboti							
Kinyoro	18	4		3			
Saboti	1	1					
Total	**37**	**18**	**5**	**5**	**2**	**1**	**1**
Propotion (%)	**33.64**	**16.36**	**4.55**	**4.55**	**1.82**	**0.91**	**0.91**

Table 5.60: Pathogenic organisms managed by the agronomic practices indicated in Figure 5.46

Sub-county	Pathogenic organisms	
	P. infestans	***R. solanacearum***
Cherangany		
Cherangani/Suwerwa	15	6
Makutano	2	2
Endebess		
Chepchoina	1	2
Endebess	5	6
Matumbei	3	4
Saboti		
Kinyoro	13	14
Saboti	16	13
Total	**55**	**47**
Proportion (%)	**50.00**	**42.73**

Table 5.61: Insects managed by the agronomic practices indicated in Figure 5.46

Sub-county	Insects						
	Aphids	White flies	Cutworms	Ants	Tuber moth	Chafer grubs	Thrips
Cherangany							
Cherangani/Suwerwa	5	4	3		2	1	
Makutano				1			
Endebess							
Chepchoina				1			
Endebess	6	1					
Matumbei	1						1
Saboti							
Kinyoro	2	8	4	4	1		
Saboti						1	
Total	**14**	**13**	**7**	**6**	**3**	**2**	**1**
Proportion (%)	**12.73**	**11.82**	**6.36**	**5.45**	**2.73**	**1.82**	**0.91**

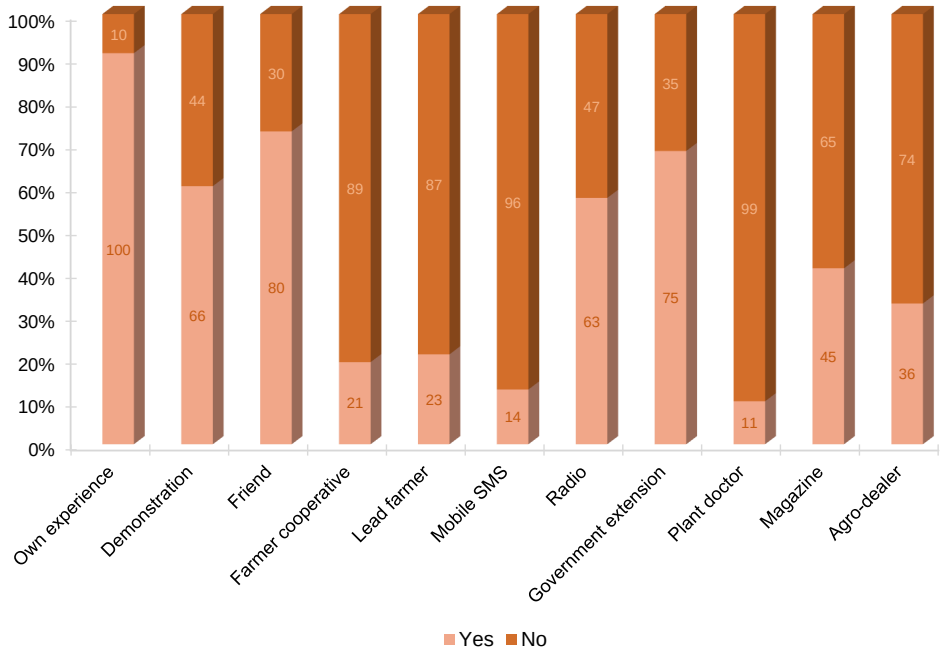


Figure 5.47: Sources of information for potato production and management of challenges in Trans Nzoia county

The agronomic practices used by most farmers included weeding (107, 97.3%), fertilizers application (105, 95.5%), recommended spacing (78, 71%), and crop rotation (65, 59.1%) (Figure 5.46). Mulching and irrigation were reported by only one and two farmers respectively. As reported in previous sections, mulching is not an essential agronomic practice for potato production while irrigation has not been reported widely outside the Mt. Kenya region. Improved seed was not reported widely (11, 10%) which correlated with the results on source of planting materials as most farmers depended on the informal seed system (Table 5.58). Crops rotated with potato included maize (33.6%) reported by most farmers followed by beans (18, 16.4%). Scouting for pests and use of various pest management strategies was widely used and focused on managing *R. solanacearum* (47, 42.7%), *P. infestans* (55, 50.0%), aphids (14, 12.7%), and whiteflies (13, 11.8%) (Table 5.60 and 5.61).

Most (100, 90.9%) of the farmers used own experience in production and management of the challenges of the crop (Figure 5.47). This is a trend that has been observed with other counties. Friend (80, 72.7%), government extension (75, 68.1%), demonstration (66, 60.0%), and radio (63, 57.3%) were selected by more than 50% of the farmers (Figure 5.47). Use of magazines and agro-dealers were selected by more than 25% of the farmers. Plant doctors where the least selected by only one in every ten farmers. This was the lowest frequency, a trend observed in all other counties partly because they are not yet widely distributed but also because they do not operate everyday but at agreed intervals (like once a week or fortnight). Bacterial ring rot was not reported to have been observed by the farmers even after they were shown images depicting the disease and its symptoms (Figure 5.10). Only three farmers identified SRP-associated diseases (blackleg and soft rots) (Table 5.11). Although the relatively low number of

observations of either disease could be attributed to the lower number of samples collected compared to Nakuru and Nyandarua, it could also be due a lack of knowledge about the pests, presence of latent infections or confusion of symptoms with other plant health problems. The farmers uprooted the blackleg-infected plants and also did nothing for soft rots. None of the farmers who identified either problem reported to extension officers which is not ideal but at least, they did not use chemicals as a management strategy which is not effective as has been observed in other counties.

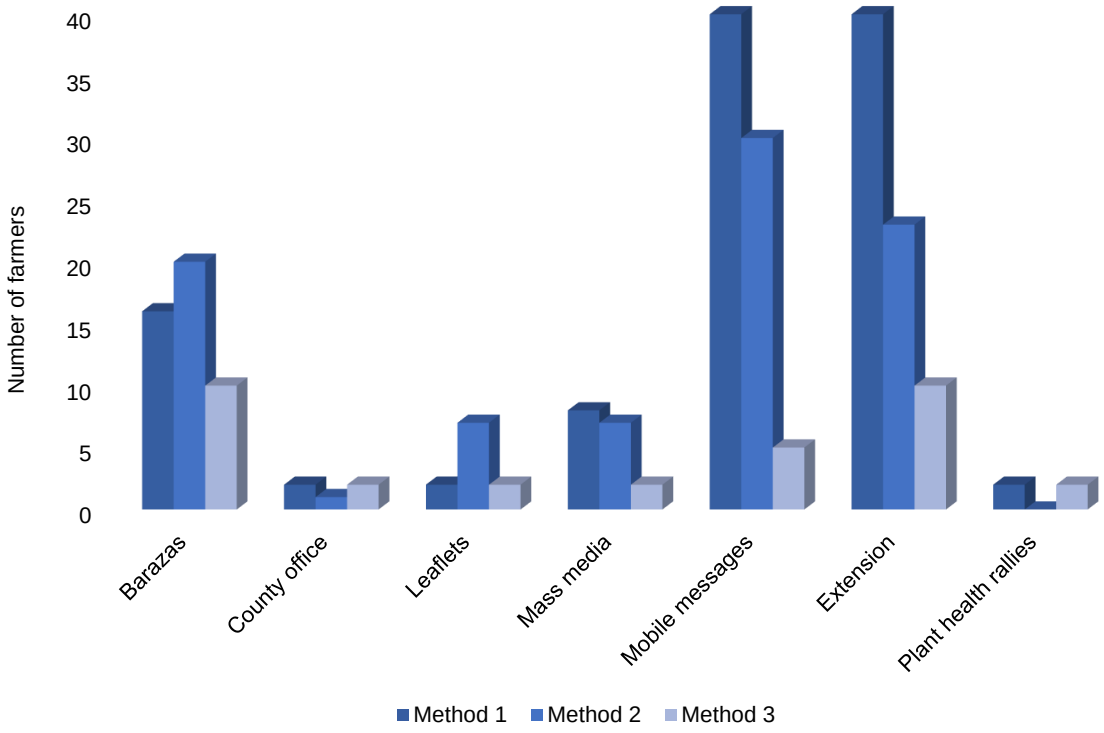


Figure 5.48: Method of choice for information dissemination in potato production in Trans Nzoia county

When asked the method of choice for information dissemination in case of an outbreak of the blackleg, soft rots or bacterial ring rot, the majority selected mobile messaging followed by extension with Barazas coming in third (Figure 5.48).

6

Molecular Diagnostics

6.1 Background

Samples were collected from 1,002 farming households in six counties (Figure 1.5). Samples included whole plants directly from the field (comprised leaves, stems and tubers); tubers (where the crop had been harvested or previous season's crop was available in storage) and soil. Soil was included because it has been reported to harbour SRP for 1 week to 6 months depending on the prevailing environmental conditions (soil temperature, moisture and pH) although they can survive much longer if volunteers are present (42). All the samples were asymptomatic for *Clavibacter sepedonicus* while the majority were asymptomatic for the SRP species. As a result, some of the samples were collected in duplicate, triplicate or quadruplicate as described in Section 4.1 to maximise chances of isolating either pathogen. On arrival at KEPHIS laboratories, all samples were processed and a total of 2,834 samples was obtained which comprised of 1,334 stem samples, 696 tuber samples and 804 soil samples. Some of the samples were discarded especially if their integrity was questionable. For instance, *S. tuberosum* being a very perishable crop, some of the samples were so rotten especially the tubers for any pathogenic isolations to be made. For soil, some samples were discarded because they were secured directly in paper bags ending up being mixed in polystyrene boxes with other soil samples when the paper bags gave way due the immense wetness in the soil. The higher number of stem samples processed in comparison to the number of households (1,002) is because some samples were obtained in duplicate, triplicate or quadruplicate as previously indicated. In addition, more stem samples were retained because their integrity was intact unlike soil and tubers. All processed samples were kept at -20^{o}C until needed for isolations.

6.2 *Clavibacter sepedonicus*

All the samples from which isolation of *C. sepedonicus* was attempted, were asymptomatic as indicated above. Isolations were done only from stem and tuber samples on MTNA medium (Appendix C.5) after which, clean colonies were transferred to YGM medium (Appendix C.9). Isolation were made from 2,030 samples comprising of 1,334 stem and 696 tuber samples resulting in 1,362 purified colonies. DNA was isolated from 1,005 of the 1,362 colonies as indicated in Chapter 4 but detailed in

Appendix G. This DNA was used as the template for conventional (end point) PCR to determine presence or absence of this bacterial pathogenic species. For the remaining 357 samples, bacterial colonies were used as the template. Two primer sets, Cms50 and Cms72a (Table 4.3) that have been extensively used in a number of studies (96, 97) were used in this study. In addition, two positive controls, NCPPB 3916 and 4218 were included in the analysis. In all the samples that were tested, there was no positive band for the samples except for the positive control (Figure 6.1).

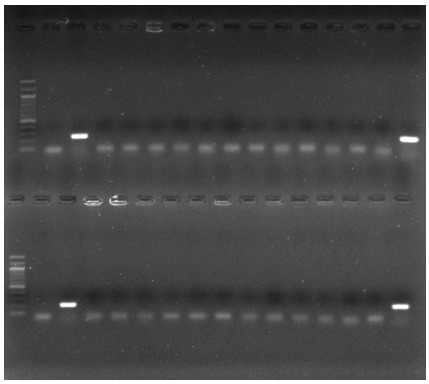


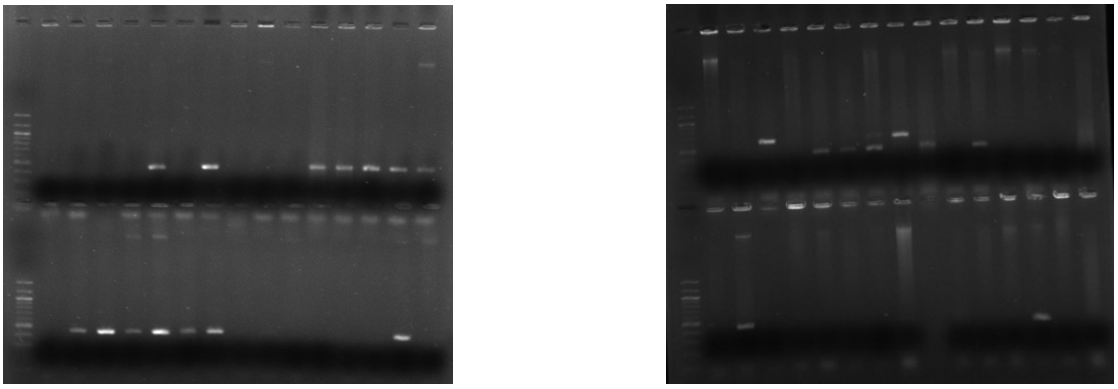
Figure 6.1: Samples tested for presence of *C. sepedonicus*

In Figure 6.1; Lane 1 contains the 100 bp ladder; Lane 2, negative control (water); Lane 3, and 16, positive controls (3916 and 4218 respectively); and Lanes 4-15 contain the samples. The same arrangement represented for both halves in the gel.

6.3 *Dickeya* and *Pectobacterium* Species

Attempts to isolate these two pathogenic species were made from stem, tuber and soil samples on semiselective media (CVP) (Appendix C.1 and C.2). CVP remains the most preferred diagnostic selective medium for isolation of SRP (74, 104–106). The selectivity of CVP is based on the presence of crystal violet which inhibits growth of most gram positive bacterial species and polypectate which is the sole source of carbon. *Dickeya* and *Pectobacterium* species form characteristic deep cup-like cavities or round pits (2-3 mm in diameter) on CVP which are different from those formed by pectolytic *Pseudomonads*, which tend to be shallower and wider (107). In addition to the 1,334 stem samples and 696 tuber samples from which *C. sepedonicus* was isolated, 804 soil samples were added and all used for isolating *Dickeya* and *Pectobacterium* species too. Because most of these samples were asymptomatic, an enrichment step was included to enrich the pathogen population above detection levels (65). This was possible by incubating the test materials under anaerobic conditions in liquid enrichment medium (D-PEM, Appendix B.14). D-PEM contains Sodium polypectate as the sole carbon source (65). Therefore, isolations where made from 2,834 samples comprising of 1,334 stem and 696 tuber and 804 soil samples resulting in 2,834 plates with bacterial growth.

As indicated in Section 4.4.2, surface growth was washed off the plates, divided into two portions both of which were kept at -20^{o}C until needed for further processing. One of the portions (approx. 500 μL) was used for molecular diagnostics while the other portion (approx. 1 mL) was used for further isolations following positive confirmation from the first portion. This approach was more time and cost effective given that the number of samples for processing was massive to take all of them through the whole process of isolation to purification. Unlike with *C. sepedonicus* where DNA was used as a template in the PCR assay in addition to heated bacterial cells, with SRP (*Dickeya* and *Pectobacterium* species), only heated bacterial cells (from portion one) were used saving time and funds. Following isolation, the first PCR assays comprising a multiplex PCR for separating *Dickeya* and *Pectobacterium* species was conducted using ECH1/ECH1′ and Y1/Y2 primers (98, 99) respectively. PCR conditions for these primer sets are presented in Table 4.3 under Section 4.6. Multiplexing these primer sets was possible because both can anneal at the same temperature which saved time and resources. Of the 2,834 samples that were tested, 291 samples (equivalent to 10.3%) turned out positive for SRP of which 290 samples (equivalent to 10.2%) turned out positive for *Pectobacterium* species. Of the 291, 63% (183) were stems, 32% (92), soil and 5% (16) were tubers. The varieties from which they were isolated comprised of Shangi (177, 89%), Dutch Robijn (18, 9%), Asante (2, 1%), Destiny (1, 1%) and Kabale (1, 1%). The majority of isolations were made from samples from Nyandarua, 65% (190 of 291) followed by Narok (16.5%, 48 of 291) then Nakuru (7.9%, 23 of 291), Meru (4.8%, 14 of 29), Elgeyo Marakwet (3.4%, 10 of 291), and Trans Nzoia (2%, 6 of 291). Only two samples turned out positive for *Dickeya* species of which one demonstrated a positive result for *Pectobacterium* species (Figure 6.2, Table 6.1 and Appendix H.1).



A **B**

Figure 6.2: Samples that tested positive for *Dickeya* and *Pectobacterium* species

Figure 6.2A and B, represents two gel images from a multiplex PCR with ECH1/ECH1′ and Y1/Y2 primer pairs. ECH1/ECH1′ confirms *Dickeya* species and amplifies a product 600 bp while Y1/Y2 confirms *Pectobacterium* species and amplifies a product 434 bp. Figure 6.2A represents samples that tested positive for *Pectobacterium* species. Lane 1 and 2 (above and below) contain the 100 bp ladder and a negative control respectively. Lane 3-16 (above and below) are samples. In Figure 6.2B, Lane 1 and 2 (above and below) contain the 100 bp ladder and a negative control respectively. Lane 4 (above), positive control, (3881, *D. dianthicola*); Lane 8, **Sample 59** and Lane 9, **Sample 762**.

Note the two bands for Sample 59, one for *Pectobacterium* species and the other for *Dickeya* species. Figure 6.2B consolidated a number of samples for confirmation.

6.3.1 *Dickeya* Species

The two samples that turned out positive for *Dickeya* species included Sample 762 (Farm 198) from Elgeyo Marakwet and Sample 59 (Farm 412) from Narok county all isolated from tubers. Both were recorded on the variety Shangi. Details of these samples are presented below in Table 6.1. Confirmation of only two samples does not indicate low frequency.

Table 6.1: Details of positive samples for *Dickeya* species

FARM NUMBER	198	412
CODE	EL-MRW-KPS-AK	NR-NRN-OLR-SK4
SAMPLE NUMBER	762	59
SAMPLE TYPE	Tuber	Tuber
VARIETY	Shangi	Shangi
COUNTY	Elgeyo Marakwet	Narok
SUB-COUNTY	Marakwet West	Narok North
WARD	Kapsowar	Oloropil
LATITUDE	0.922018653	-0.759709426
LONGITUDE	35.56313775	35.88936796
ALTITUDE	2361	2600

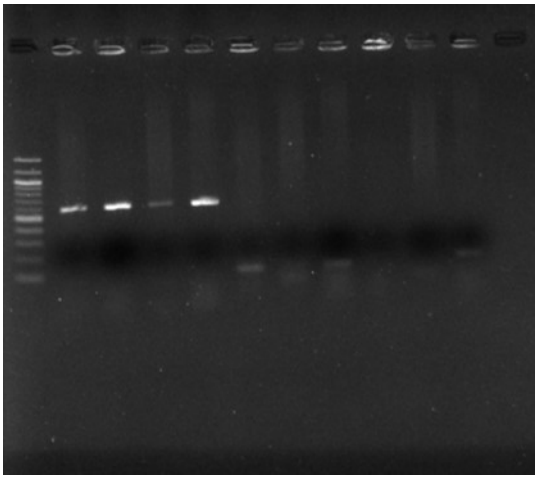


Figure 6.3: Samples that tested positive for *Dickeya* species

Figure 6.3, represents end point PCR gel image for samples that gave a positive band with the ECH1/ECH1′ primer pair in the multiplex PCR gel presented in Figure 6.2B. Lane 1 represents the 100 bp ladder; Lane 2 and 3, positive controls, 3881 (*D. dianthicola*), 4479 (*D. solani*); Lane 4, **Sample 59** and Lane 5, **Sample 762** (Table 6.1). Lane 6-11, samples that gave a band with Y1/Y2 but not ECH1/ECH1′.

Additional surveillance in Elgeyo Marakwet and Narok counties (Appendix I) underscored the presence of *Dickeya* and identified one of the samples as *D. solani*. Surveillance by KALRO in Taita Taveta county (Appendix J) provides further confirmation of presence of the *Dickeya* genus in Kenya having identified *D. solani* and *D. dianthicola*.

6.3.2 *Pectobacterium* Species

Following the initial confirmation, the 290 samples that demonstrated a positive result with primer Y1 and Y2 were subjected to more PCR assays but with species-specific primers. The species tested included *P. atrosepticum*; *P. brasiliense*; *P. carotovorum*; and *P. parmentieri*. *P. parmentieri* which has been previously reported in Kenya (17) was not tested for lack of its specific primers. The primer sets used are presented in Table 4.3 but were ECA1/ECA2 and Y45/Y46 for *P. atrosepticum* (99, 100); EXPCCF/EXPCCR for *P. carotovorum* (66, 101); BR1f/L1r for *P. brasiliense* (102); PW7011F/PW7011R for *P. parmentieri* (103). PCR conditions for these primer sets are also presented in Table 4.3 under Section 4.6. Of the 290 samples, 29 samples (equivalent to 10.0%) tested positive for *P. atrosepticum*; 46 samples (equivalent to 15.6%) tested positive for *P. brasiliense*; 39 samples (equivalent to 13.5%) tested positive for *P. carotovorum*; and 51 samples (equivalent to 17.6%) tested positive for *P. parmentieri*.

Pectobacterium atrosepticum

The 29 samples which turned out positive for *P. atrosepticum*, they included 9 soil and 20 stem samples. The samples from which this species was confirmed came from all the counties with the majority coming from Nyandarua county (16) followed by Meru, Nakuru and Narok which had 2 samples and each and lastly Elgeyo Marakwet and Trans Nzoia each of which had two samples. The varieties included Shangi (25), Dutch Robijn (3) and Asante (1). Detailed results presented in Table 6.2.

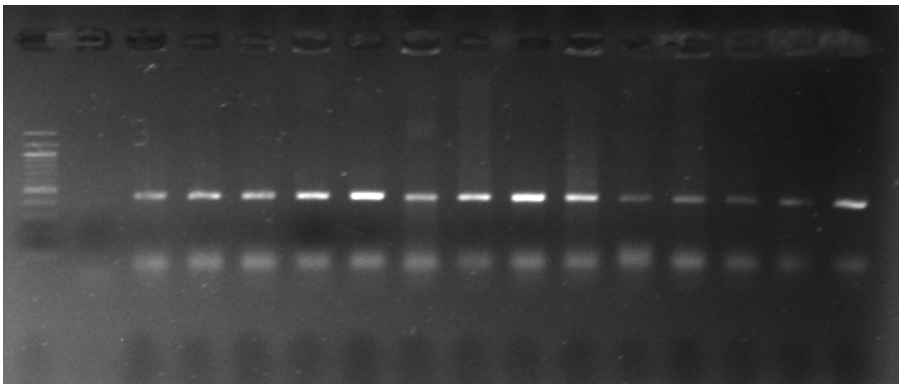


Figure 6.4: Samples that tested positive for *P. atrosepticum*

Figure 6.4 represents the gel image resulting from a diagnostic PCR for *P. atrosepticum*. Lane 1 contains the 100 bp ladder; Lane 2 a negative control (water); Lane 3, positive control (4636); Lane 4-16, the samples that tested positive. The expected band of around 439 bp with Y45/46 primer pair was obtained. Note, samples that tested positive in various PCR assays were consolidated in one PCR for illustration.

Pectobacterium brasiliense

The 46 samples for which *P. carotovorum* subsp. *brasiliense* was confirmed comprised of 16 soil samples, 28 stem sample and 2 tuber samples. The plant samples came from the varieties of Dutch Robijn (9) and Shangi (37). They came from four counties with Nyandarua recording the highest (34) followed by Narok (10) with Elgeyo Marakwet and Meru each recording one. The absence of Nakuru and Trans Nzoia does not imply absence of this sub-species in these counties. Detailed results presented in Table 6.3.

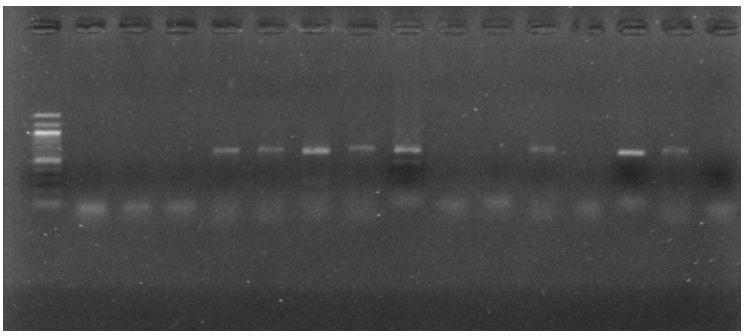


Figure 6.5: Samples that tested positive for *P. brasiliense*

An example from one of the diagnostic PCRs. Lane 1 contains the 100 bp ladder; Lane 2 a negative control (water); Lane 3-16, contain the samples. The expected 690 bp band with BR1f/L1r primer pair was obtained.

Pectobacterium carotovorum

The 39 samples for which thus subspecies was confirmed comprised of 27 stem, 11 soil, and 1 tuber sample. The plant samples were from Shangi (31), Dutch Robijn (7) and Kabale (1) and came from all counties with Nyandarua recording the highest (24) followed by Narok (10). Figure 6.6 presents an example from one of the diagnostic PCRs. Above and below; Lane 1 contains the 100 bp ladder; Lane 2 a negative control (water); Lane 3, positive control (3398); Lane 4-16 (above and below), samples. The expected 550 bp band in some and 400 bp band in other strains with EXPCCF/EXPCCR primer pair was obtained.

Pectobacterium parmentieri

P. wasabiae was confirmed in 39 samples which comprised 34 stem samples, 13 soil samples, and 4 tuber samples. The plant samples were from the varieties of Shangi (44), Dutch Robijn (6) and Destiny (1) and came from the counties of Nyandarua which had the highest (28) followed by Narok (17), Elgeyo Marakwet (3), Meru (2) and Trans Nzoia (1). Figure 6.7 presents an example from one of the diagnostic PCRs. Lane 1 (above and below) contains the 100 bp ladder; Lane 2-16 (above and below) contain the samples that were tested. The expected band of around 140 bp with PW7011F/PW7011R primer pair was obtained as can be observed in almost all samples although more conspicuous in lanes 2-4, 12-13 and 15-16 (above) and 2-4, 8, 13 and 15-16 (below).

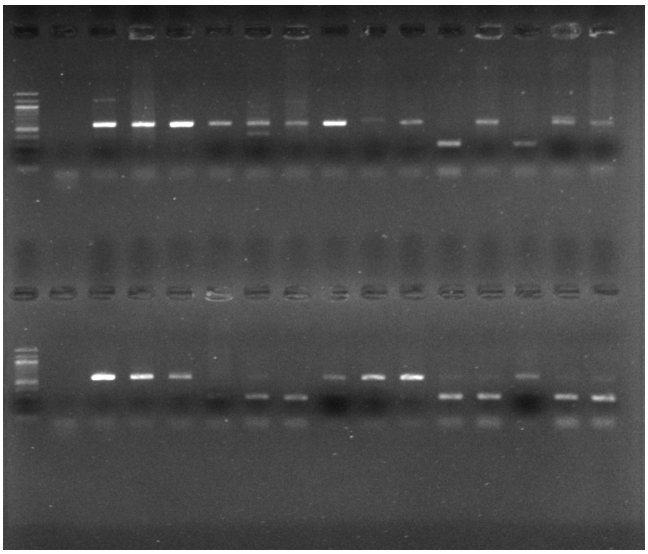


Figure 6.6: Samples that tested positive for *P. carotovorum*

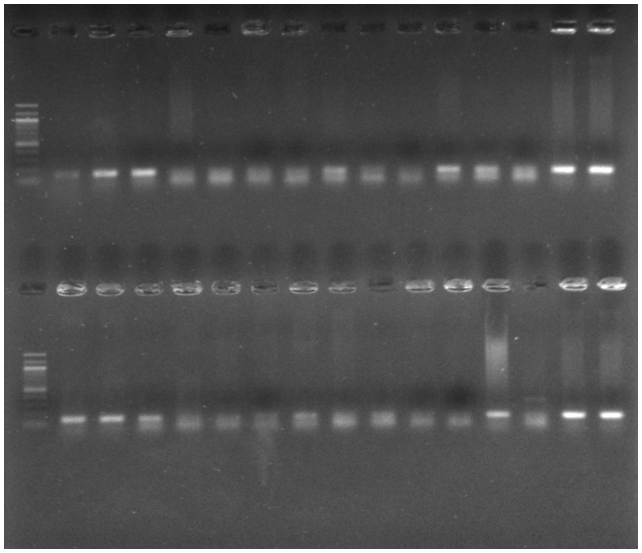


Figure 6.7: Samples that tested positive for *P. parmentieri*

Multiple species and subspecies

Farm 412 from which Sample 59 was obtained, also had two other samples, 177 and 860. The two samples also tested positive for the genus *Pectobacterium*. Species-specific primers confirmed Sample 177 to be a *P. brasiliense* (Table 6.6). In addition, different subspecies were also confirmed in the same sample or from different samples obtained from the same farm (Table 6.6). Up to three different sub-species were confirmed from one sample. Similar species were also confirmed in plant and from soil samples obtained from the same farm. Examples include Farm 393, 496, 498, 672, 727 and 882 (Table 6.6)

Table 6.2: Samples confirmed to be infected with *Pectobacterium atrosepticum*

No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	*Pectobacterium* sp.	*Pa*
1	23	2138	MR-IMC-ABT-DK	Meru	Imenti Central	Abothuguchi West	Stem	Shangi	+ve	+ve
2	82	1882	MR-BRI-KBR-JK3	Meru	Buuri	Kibirichia	Soil		+ve	+ve
3	84	1919	MR-BRI-KSM-EK	Meru	Buuri	Kisima	Soil		+ve	+ve
4	181	1686	EL-MRE-KPY-TC	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve	+ve
5	186	1998	EN-MRE-KPY-JM	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve	+ve
6	360	1955	TN-SBT-SBT-EW	Trans Nzoia	Saboti	Saboti	Stem	Asante	+ve	+ve
7	363	1980	TN-SBT-SBT-MK	Trans Nzoia	Saboti	Saboti	Stem	Shangi	+ve	+ve
8	476	137	NR-NRE-IDM-JM	Narok	Narok East	Iidamat	Stem	Shangi	+ve	+ve
9	498	132	NR-NRS-SGO-WK1	Narok	Narok South	Sogoo	Soil		+ve	+ve
10	505	610	NR-NRE-IDM-DM	Narok	Narok East	Iidamat	Soil		+ve	+ve
11	534	371	NY-OLK-RRI-PM2	Nyandarua	Ol Kalou	Rurii	Soil		+ve	+ve
12	546	454	NY-OLK-MRN-CK	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
13	587	456	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve	+ve
14	592	113	NY-NDR-SHM-BM	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve	+ve
15	629	609	NY-OLJ-GTH-LM	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve	+ve
16	640	97	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
17	665	855	NY-KPR-KPR-LM	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve	+ve
18	687	450	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Soil		+ve	+ve
19	687	619	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
20	695	1219	NY-KPR-WNJ-DC	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
21	719	1100	NY-KPR-NYK-PK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
22	721	927	NY-KPR-NYK-CN	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
23	727	260	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
24	790	259	NY-KPR-MGM-MK	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve	+ve
25	841	429	NY-KPR-GTA-GM	Nyandarua	Kipipiri	Geta	Soil		+ve	+ve
26	882	235	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Stem	Dutch Robijn	+ve	+ve
27	953	2270	NK-NJR-MCH-JS1	Nakuru	Njoro	Mauche	Stem	Dutch Robijn	+ve	+ve
28	959	2152	NK-NJR-NSS-AC1	Nakuru	Njoro	Nessuit	Stem	Shangi	+ve	+ve
29	1186	1434	NK-KRS-KRN-BC	Nakuru	Kuresoi South	Keringet	Soil		+ve	+ve

Table 6.3: Samples confirmed to be infected with *Pectobacterium brasiliense*

No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	*Pectobacterium* sp.	*Pb*
1	84	1919	MR-BRI-KSM-EK	Meru	Buuri	Kisima	Soil		+ve	+ve
2	187	144	EL-MRE-KPY-TM	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve	+ve
3	393	161	NR-NRS-SGM-SC	Narok	Narok South	Sagamian	Stem	Dutch Robijn	+ve	+ve
4	412	177	NR-NRN-OLR-SK4	Narok	Narok North	Oloropil	Stem	Shangi	+ve	+ve
5	414	332	NR-NRN-OLR-JS	Narok	Narok North	Oloropil	Stem	Shangi	+ve	+ve
6	419	910	NR-NRN-OLR-RY	Narok	Narok North	Oloropil	Soil		+ve	+ve
7	420	544	NR-NRN-OLR-SK2	Narok	Narok North	Oloropil	Soil		+ve	+ve
8	447	512	NR-NRN-MLL-PJ	Narok	Narok North	Melili	Soil		+ve	+ve
9	450	178	NR-NRN-MLL-JT1	Narok	Narok North	Melili	Stem	Shangi	+ve	+ve
10	459	400	NR-NRE-KKN-AK	Narok	Narok East	Keekonyokie	Soil		+ve	+ve
11	490	170	NR-NRS-SGO-HK	Narok	Narok South	Sogoo	Stem	Dutch Robijn	+ve	+ve
12	496	40	NR-NRS-SGO-MS	Narok	Narok South	Sogoo	Tuber	Dutch Robijn	+ve	+ve
13	521	234	NY-OLK-RRI-SK	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve	+ve
14	529	82	NY-OLK-RRI-HM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve	+ve
15	534	371	NY-OLK-RRI-PM2	Nyandarua	Ol Kalou	Rurii	Soil		+ve	+ve
16	543	92	NY-OLK-MRN-MW	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
17	555	612	NY-OLK-MRN-SW1	Nyandarua	Ol Kalou	Mirangine	Soil		+ve	+ve
18	574	251	NY-OLK-KNJ-LM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve	+ve
19	592	113	NY-NDR-SHM-BM	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve	+ve
20	611	256	NY-NDR-SHM-PM2	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve	+ve
21	620	122	NY-OLJ-GTH-LI	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve	+ve
22	640	97	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
23	648	79	NY-NDR-KRT-MK1	Nyandarua	Ndaragwa	Kiriita	Tuber	Shangi	+ve	+ve
24	653	213	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
25	653	225	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
26	659	240	NY-KPR-KPR-IM	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve	+ve
27	661	389	NY-KPR-KPR-HM	Nyandarua	Kipipiri	Kipipiri	Soil		+ve	+ve
28	663	236	NY-KPR-KPR-JK1	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve	+ve
29	672	507	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Soil		+ve	+ve
30	672	249	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve	+ve
31	687	619	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	*Pectobacterium* sp.	*Pb*
32	705	539	NY-KPR-WNJ-LM1	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
33	721	927	NY-KPR-NYK-CN	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
34	727	1198	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Soil		+ve	+ve
35	765	140	NY-KPR-MGM-SN	Nyandarua	Kipipiri	Magumu	Soil		+ve	+ve
36	780	231	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Stem	Dutch Robijn	+ve	+ve
37	790	259	NY-KPR-MGM-MK	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve	+ve
38	818	195	NY-OLJ-CHR-JK	Nyandarua	Ol Joro Orok	Charagita	Soil		+ve	+ve
39	841	429	NY-KPR-GTA-GM	Nyandarua	Kipipiri	Geta	Soil		+ve	+ve
40	849	960	NY-KPR-GTA-SM2	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve	+ve
41	857	211	NY-OLJ-WRU-EW	Nyandarua	Ol Joro Orok	Weru	Stem	Shangi	+ve	+ve
42	871	1089	NY-KNG-MRG-JN3	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve	+ve
43	878	342	NY-KNG-NKG-PK	Nyandarua	Kipipiri	North Kinangop	Soil		+ve	+ve
44	880	536	NY-KNG-NKG-RK	Nyandarua	Kinangop	North Kinangop	Soil		+ve	+ve
45	882	523	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Soil		+ve	+ve
46	882	235	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Stem	Dutch Robijn	+ve	+ve

Table 6.4: Samples confirmed to be infected with *Pectobacterium carotovorum*

No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	*Pectobacterium* sp.	*Pc*
1	84	1919	MR-BRI-KSM-EK	Meru	Buuri	Kisima	Soil		+ve	+ve
2	114	1900	MR-BRI-KBR-AN	Meru	Buuri	Kibirichia	Soil		+ve	+ve
3	186	1998	EN-MRE-KPY-JM	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve	+ve
4	365	1613	TN-SBT-SBT-JM	Trans Nzoia	Saboti	Saboti	Stem	Kabale	+ve	+ve
5	394	784	NR-NRS-SGM-JR2	Narok	Narok South	Sagamian	Tuber	Dutch Robijn	+ve	+ve
6	449	542	NR-NRN-MLL-NS	Narok	Narok North	Melili	Soil		+ve	+ve
7	450	178	NR-NRN-MLL-JT1	Narok	Narok North	Melili	Stem	Shangi	+ve	+ve
8	457	175	NR-NRE-KKN-DS2	Narok	Narok East	Keekonyokie	Stem	Shangi	+ve	+ve
9	478	552	NR-NRE-KKN-MK	Narok	Narok East	Keekonyokie	Soil		+ve	+ve
10	490	170	NR-NRS-SGO-HK	Narok	Narok South	Sogoo	Stem	Dutch Robijn	+ve	+ve
11	496	926	NR-NRS-SGO-MS	Narok	Narok South	Sogoo	Soil		+ve	+ve
12	498	398	NR-NRS-SGO-WK1	Narok	Narok South	Sogoo	Soil		+ve	+ve
13	501	304	NR-NRS-SGO-WS	Narok	Narok South	Sogoo	Stem	Dutch Robijn	+ve	+ve
14	511	1558	NR-NRE-IDM-MK	Narok	Narok East	Iidamat	Soil		+ve	+ve
15	517	322	NY-OLK-RRI-MM	Nyandarua	Ol Kalou	Rurii	Soil		+ve	+ve
16	529	82	NY-OLK-RRI-HM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve	+ve
17	541	262	NY-OLK-MRN-JM	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
18	546	454	NY-OLK-MRN-CK	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
19	562	228	NY-OLK-MRN-MN	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
20	573	344	NY-OLK-KNJ-SN	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve	+ve
21	617	129	NY-OLJ-GTH-JM3	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve	+ve
22	631	245	NY-OLJ-GTH-DG	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve	+ve
23	640	97	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
24	642	179	NY-NDR-KRT-CK	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
25	653	213	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
26	663	236	NY-KPR-KPR-JK1	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve	+ve
27	672	249	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve	+ve
28	687	450	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Soil		+ve	+ve
29	687	619	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
30	695	1219	NY-KPR-WNJ-DC	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
31	698	921	NY-KPR-WNJ-PN	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	*Pectobacterium* sp.	*Pc*
32	705	539	NY-KPR-WNJ-LM1	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
33	719	1256	NY-KPR-NYK-PK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
34	761	168	NY-KNG-MGM-LG	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve	+ve
35	780	231	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Stem	Dutch Robijn	+ve	+ve
36	790	259	NY-KPR-MGM-MK	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve	+ve
37	857	211	NY-OLJ-WRU-EW	Nyandarua	Ol Joro Orok	Weru	Stem	Shangi	+ve	+ve
38	882	235	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Stem	Dutch Robijn	+ve	+ve
39	939	2222	NK-NVS-BSH-PN2	Nakuru	Naivasha	Biashara	Stem	Shangi	+ve	+ve

Table 6.5: Samples confirmed to be infected with *Pectobacterium parmentieri*

No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	*Pectobacterium* sp.	*Pp*
1	167	1622	EL-KYN-KMR-HK	Elgeyo Marakwet	Keiyo North	Kamariny	Stem	Shangi	+ve	+ve
2	181	1686	EL-MRE-KPY-TC	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve	+ve
3	186	1998	EN-MRE-KPY-JM	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve	+ve
4	363	1980	TN-SBT-SBT-MK	Trans Nzoia	Saboti	Saboti	Stem	Shangi	+ve	+ve
5	393	902	NR-NRS-SGM-SC	Narok	Narok South	Sagamian	Soil		+ve	+ve
6	394	784	NR-NRS-SGM-JR2	Narok	Narok South	Sagamian	Tuber	Dutch Robijn	+ve	+ve
7	396	924	NR-NRS-SGM-SS	Narok	Narok South	Sagamian	Soil		+ve	+ve
8	419	910	NR-NRN-OLR-RY	Narok	Narok North	Oloropil	Soil		+ve	+ve
9	420	345	NR-NRN-OLR-SK2	Narok	Narok North	Oloropil	Stem	Shangi	+ve	+ve
10	442	863	NR-NRN-MLL-SS	Narok	Narok North	Melili	Stem	Shangi	+ve	+ve
11	444	550	NR-NRN-MLL-BI	Narok	Narok North	Melili	Soil		+ve	+ve
12	449	542	NR-NRN-MLL-NS	Narok	Narok North	Melili	Soil		+ve	+ve
13	450	178	NR-NRN-MLL-JT1	Narok	Narok North	Melili	Stem	Shangi	+ve	+ve
14	471	52	NR-NRE-IDM-PN	Narok	Narok East	Iidamat	Tuber	Shangi	+ve	+ve
15	473	395	NR-NRE-KKN-JN	Narok	Narok East	Keekonyokie	Soil		+ve	+ve
16	476	152	NR-NRE-IDM-JM	Narok	Narok East	Iidamat	Stem	Shangi	+ve	+ve
17	490	170	NR-NRS-SGO-HK	Narok	Narok South	Sogoo	Stem	Dutch Robijn	+ve	+ve
18	497	279	NR-NRS-SGO-AK	Narok	Narok South	Sogoo	Stem	Destiny	+ve	+ve
19	498	398	NR-NRS-SGO-WK1	Narok	Narok South	Sogoo	Soil		+ve	+ve
20	511	1558	NR-NRE-IDM-MK	Narok	Narok East	Iidamat	Soil		+ve	+ve
21	512	60	NR-NRE-IDM-PK	Narok	Narok East	Iidamat	Tuber	Shangi	+ve	+ve
22	521	234	NY-OLK-RRI-SK	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve	+ve
23	529	82	NY-OLK-RRI-HM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve	+ve
24	541	262	NY-OLK-MRN-JM	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
25	552	614	NY-OLK-MRN-JK	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
26	560	930	NY-OLK-ML-BN	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve	+ve
27	577	623	NY-OLK-KNJ-MW	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve	+ve
28	587	456	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve	+ve
29	594	237	NY-NDR-SHM-PK2	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve	+ve
30	605	91	NY-NDR-CNT-JN2	Nyandarua	Ndaragwa	Central	Stem	Shangi	+ve	+ve
31	622	121	NY-OLJ-GTH-JR	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve	+ve

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	*Pectobacterium* sp.	*Pp*
32	627	80	NY-OLJ-GTH-AM2	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve	+ve
33	640	500	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
34	648	79	NY-NDR-KRT-MK1	Nyandarua	Ndaragwa	Kiriita	Tuber	Shangi	+ve	+ve
35	653	213	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
36	653	225	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve	+ve
37	672	249	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve	+ve
38	687	450	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Soil		+ve	+ve
39	696	1248	NY-KPR-WNJ-PG	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
40	698	875	NY-KPR-WNJ-PN	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve	+ve
41	709	241	NY-KPR-NYK-SK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
42	714	1039	NY-KPR-NYK-JC	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
43	727	530	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve	+ve
44	761	168	NY-KNG-MGM-LG	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve	+ve
45	784	387	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Soil		+ve	+ve
46	796	99	NY-KPR-MGM-LN	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve	+ve
47	822	373	NY-OLJ-CHR-MM	Nyandarua	Ol Joro Orok	Charagita	Soil		+ve	+ve
48	836	380	NY-OLJ-WRU-LN	Nyandarua	Ol Joro Orok	Weru	Soil		+ve	+ve
49	877	440	NY-KNG-NKG-TW	Nyandarua	Kinangop	North Kinangop	Stem	Dutch Robijn	+ve	+ve
50	1091	2200	NK-MLO-MLO-JM1	Nakuru	Molo	Molo	Stem	Shangi	+ve	+ve
51	1194	2340	NK-KRS-AML-RR	Nakuru	Kuresoi South	Amalo	Stem	Shangi	+ve	+ve

Table 6.6: Samples confirmed to be infected with multiple *Pectobacterium* subspecies

No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRP		Subspecies			
									***Pectobacterium* spp.**	***Dickeya* spp.**	***Pa***	***Pb***	***Pc***	***Pp***
1	84	1919	MR-BRI-KSM-EK	Meru	Buuri	Kisima	Soil		+ve		+ve	+ve	+ve	
2	181	1686	EL-MRE-KPY-TC	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve		+ve			+ve
3	186	1998	EN-MRE-KPY-JM	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve		+ve		+ve	+ve
4	363	1980	TN-SBT-SBT-MK	Trans Nzoia	Saboti	Saboti	Stem	Shangi	+ve		+ve			+ve
5	393	161	NR-NRS-SGM-SC	Narok	Narok South	Sagamian	Stem	Dutch Robijn	+ve			+ve		
6	393	902	NR-NRS-SGM-SC	Narok	Narok South	Sagamian	Soil		+ve					+ve
7	394	784	NR-NRS-SGM-JR2	Narok	Narok South	Sagamian	Tuber	Dutch Robijn	+ve				+ve	+ve
8	412	59	NR-NRN-OLR-SK4	Narok	Narok North	Oloropil	Tuber	Shangi	+ve	+ve				
9	412	177	NR-NRN-OLR-SK4	Narok	Narok North	Oloropil	Stem	Shangi	+ve			+ve		
10	412	860	NR-NRN-OLR-SK4	Narok	Narok North	Oloropil	Stem	Shangi	+ve					
11	419	910	NR-NRN-OLR-RY	Narok	Narok North	Oloropil	Soil		+ve			+ve		+ve
12	449	542	NR-NRN-MLL-NS	Narok	Narok North	Melili	Soil		+ve				+ve	+ve
13	450	178	NR-NRN-MLL-JT1	Narok	Narok North	Melili	Stem	Shangi	+ve			+ve	+ve	+ve
14	476	137	NR-NRE-IDM-JM	Narok	Narok East	Iidamat	Stem	Shangi	+ve		+ve			
15	476	152	NR-NRE-IDM-JM	Narok	Narok East	Iidamat	Stem	Shangi	+ve					+ve
16	490	170	NR-NRS-SGO-HK	Narok	Narok South	Sogoo	Stem	Dutch Robijn	+ve			+ve	+ve	+ve
17	496	40	NR-NRS-SGO-MS	Narok	Narok South	Sogoo	Tuber	Dutch Robijn	+ve			+ve		
18	496	926	NR-NRS-SGO-MS	Narok	Narok South	Sogoo	Soil		+ve				+ve	
19	498	132	NR-NRS-SGO-WK1	Narok	Narok South	Sogoo	Soil		+ve		+ve			
20	498	398	NR-NRS-SGO-WK1	Narok	Narok South	Sogoo	Soil		+ve				+ve	+ve
21	511	382	NR-NRE-IDM-MK	Narok	Narok East	Iidamat	Soil		+ve					
22	511	1558	NR-NRE-IDM-MK	Narok	Narok East	Iidamat	Soil		+ve				+ve	+ve
23	521	234	NY-OLK-RRI-SK	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve			+ve		+ve
24	529	82	NY-OLK-RRI-HM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve			+ve	+ve	+ve
25	529	1216	NY-OLK-RRI-HM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve					
26	534	371	NY-OLK-RRI-PM2	Nyandarua	Ol Kalou	Rurii	Soil		+ve		+ve	+ve		
27	541	262	NY-OLK-MRN-JM	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve				+ve	+ve
28	546	454	NY-OLK-MRN-CK	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve		+ve		+ve	
29	587	340	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve					
30	587	341	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve					
31	587	456	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve		+ve			+ve
32	587	567	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve					
33	592	96	NY-NDR-SHM-BM	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
34	592	113	NY-NDR-SHM-BM	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve		+ve	+ve		
35	640	97	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve		+ve	+ve	+ve	
36	640	500	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve					+ve

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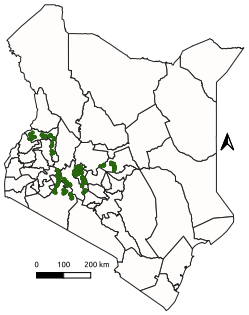
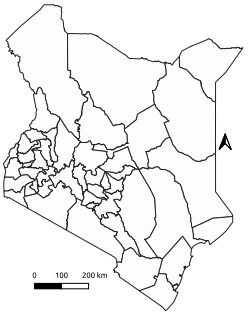
No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRP		Subspecies			
									Pectobacterium spp.	*Dickeya* spp.	*Pa*	*Pb*	*Pc*	*Pp*
37	648	79	NY-NDR-KRT-MK1	Nyandarua	Ndaragwa	Kiriita	Tuber	Shangi	+ve			+ve		+ve
38	653	213	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve			+ve	+ve	+ve
39	653	225	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve			+ve		+ve
40	653	601	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve					
41	663	236	NY-KPR-KPR-JK1	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve			+ve	+ve	
42	672	249	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve			+ve	+ve	+ve
43	672	507	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Soil		+ve			+ve		
44	687	450	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Soil		+ve		+ve		+ve	+ve
45	687	619	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve		+ve	+ve	+ve	
46	695	1219	NY-KPR-WNJ-DC	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve		+ve		+ve	
47	698	875	NY-KPR-WNJ-PN	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve					+ve
48	698	921	NY-KPR-WNJ-PN	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve				+ve	
49	705	539	NY-KPR-WNJ-LM1	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve			+ve	+ve	
50	719	1100	NY-KPR-NYK-PK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve		+ve			
51	719	1256	NY-KPR-NYK-PK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve				+ve	
52	721	927	NY-KPR-NYK-CN	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve		+ve	+ve		
53	727	260	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve		+ve			
54	727	530	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					+ve
55	727	1198	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Soil		+ve			+ve		
56	761	168	NY-KNG-MGM-LG	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve				+ve	+ve
57	761	1019	NY-KNG-MGM-LG	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve					
58	780	231	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Stem	Dutch Robijn	+ve			+ve	+ve	
59	790	259	NY-KPR-MGM-MK	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve		+ve	+ve	+ve	
60	790	412	NY-KPR-MGM-MK	Nyandarua	Kipipiri	Magumu	Soil		+ve					
61	841	429	NY-KPR-GTA-GM	Nyandarua	Kipipiri	Geta	Soil		+ve		+ve	+ve		
62	857	211	NY-OLJ-WRU-EW	Nyandarua	Ol Joro Orok	Weru	Stem	Shangi	+ve			+ve	+ve	
63	871	1089	NY-KNG-MRG-JN3	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve			+ve		
64	871	1157	NY-KNG-MRG-JN3	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve					
65	882	235	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Stem	Dutch Robijn	+ve		+ve	+ve	+ve	
66	882	523	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Soil		+ve			+ve		

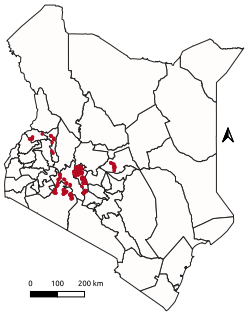
Summary of all results



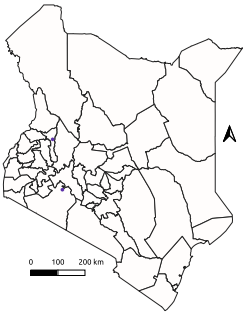
Location of all samples tested



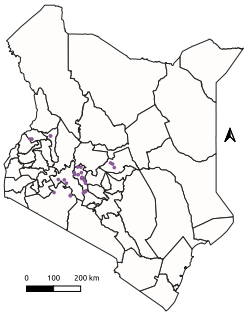
All tested negative for *C. sepedonicus*



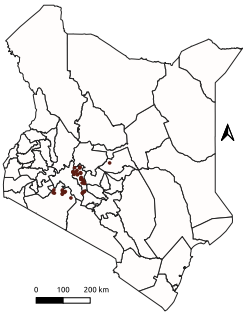
Farms that tested positive for Blackleg and Soft rots



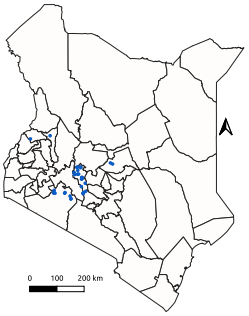
Dickeya species in Narok Elgeyo Marakwet



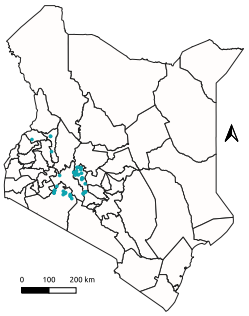
Pectobacterium atrosepticum



Pectobacterium brasiliensis



Pectobacterium carotovorum



Pectobacterium parmentieri

Figure 6.8: Status of target pathogens in the targeted counties.

7

Discussion, Conclusion and Recommendations

7.1 Purpose of the surveillance

The purpose of this extensive surveillance exercise was to assist the phytosanitary and seed regulatory authorities in Kenya in early detection of pests that are of quarantine significance; and to ensure that seed certification practices are aligned with emerging risk factors. This will contribute towards increased awareness of the country's pest status, better pest prioritization and increased investments in critical pest risks. Ultimately, this will potentially improve pest management practices of authorities and market actors, drive increased availability of quality seed hence improving potato productivity, incomes and therefore food security. To reiterate, the specific objectives of the surveillance were;

(i) Determine the presence and distribution of bacteria that cause blackleg and soft rots (*Dickeya* sp. and *Pectobacterium* spp.) and bacterial ring rot (*C. sepedonicus*).

(ii) Generate data and develop information that define risks and mitigation measures in seed supply systems (production, multiplication and distribution) for industry actors and farmers.

(iii) Enable prioritization of risk-based regulatory actions as part of official controls in seed multiplication and supply systems for Kenya.

(iv) Support objective analysis of the current regulatory framework for certification of seed potato and develop/apply control/prevention measures necessary for quality assurance elements of a potato seed health management strategy.

The work focused on key pests known to affect the potato value chain: ring rot, blackleg and soft rot. Ring rot is caused by the gram-positive rod-shaped, aerobic non-sporulating plant-pathogenic bacterium, *C. sepedonicus*, whereas blackleg and soft rots are caused by gram-negative bacteria that belong to the genera *Dickeya* and *Pectobacterium*. While *C. sepedonicus* has a postulated possible effect on the quality and quantity of seed, the genera *Dickeya* and *Pectobacterium* have an effect on the yield for all types of potato. The surveillance was aimed at determining the presence of these pathogens in the country. For *Dickeya* and *Pectobacterium*, the work also

focused on identifying the subspecies/pathovars that are present. The surveillance was conducted in six counties which included Elgeyo Marakwet, Meru, Nakuru, Narok, Nyandarua and Trans Nzoia. Meru, Nakuru and Nyandarua are considered the leading producers of potato in the country. These counties were selected through a consultative process led by KEPHIS. The six counties were selected based on criteria which included prominence in potato production, and suspected high pest pressure increasing the chance of finding the target pathogens. In addition to collection of samples, a structured questionnaire was distributed among farmers selected by the County authorities, to better understand the farming systems potentially affected by the target pathogens.

7.2 Discussion

The farmers who participated in the surveillance exercise were mainly small-scale potato growers which was expected as they were specifically selected by the WAOs and CDAs as explained in Chapters 3 and 4. Although almost equal proportions of the female and male respondents were observed, this does not indicate that there were equal proportions of female and male who headed households that grew the crop. It was due to the person who was present at the time to answer the questions. However, it gave us good insights in the views either sex had on this value chain. In total, 28 varieties were grown across all counties with 16 selected as their first choice. Shangi was grown by the majority of farmers followed in the distant second by Dutch Robijn. Mumia et al. (108) also reported Shangi being the most grown variety in Nyandarua and Kiambu counties. According to the Potato Catalogue 2019, Shangi is an early maturing variety grown for chips in a wide range of areas[4] probably explaining the wise adoption. Dutch Robijn was found to do well in a couple counties[5] although was better suited for Bomet. The majority of farmers obtained seed through informal means especially from fellow farmers, using own saved seed and from the market. Use of seed from the informal sector is not new as it has previously been reported by Mumia et al. (108) in Nyandarua and Kiambu; Muthoni et al. (8) and Kinyua et al. (7). Only 17 in 100 farmers sourced seed from seed producers. In Section 1.3, the main causes of poor usage of certified seed that need addressing such as low availability of certified seed, high prices, poor distribution networks, lack of information about the advantages of certified seed and limited availability of seed for preferred varieties were explained in detail.

All farmers interviewed claimed to use appropriate agronomic practices such as maintaining recommended spacing, use of fertilizers, weeding, and rotations which is contrary to earlier reports as presented in Section 1.3.3. A number of previous reports have reported limited usage of irrigation which is mainly concentrated around Mt. Kenya. This was too observed in this study where irrigation was only reported by a couple of farmers in Meru. Most of the farmers relied on own experience in potato production which is understandable because these are traditional potato growing regions and these farmers receive support from many actors in the value chain on potato production. The farmers also indicated scouting for pests and also

[4] Bomet, Elgeyo Marakwet, Kericho, Kiambu, Kisii, Kwale, Laikipia, Meru, Nakuru, Nandi, Narok, Nyandarua, Nyeri, Taita-Taveta, Trans-Nzoia, Uasin Gishu, and West Pokot

[5] Bomet, Kiambu, Meru, Nakuru, Nyandarua, Nyeri, Cherangani hills, Taita-Taveta, Trans-Nzoia, Uasin Gishu, and West Pokot

applied appropriate pest management strategies to manage *A. solani*, *P. infestans*, *R. solanacearum*, aphids, cutworms, whiteflies. However, very few of the farmers identified either of the target diseases even after being shown images depicting the symptoms of the pest organisms. In addition, very few farmers indicated either of the diseases (blackleg, soft rots and ring rot) as targets for management with the various agronomic practices. The low observations of blackleg and soft rots do not indicate absence of the disease but most probably a confusion of symptoms, lack of knowledge about the pest or the frequent occurrence of latent infections. Some of those who observed the diseases, did nothing to control them, which is not advisable as it results in spread of these causal pests. Some farmers uprooted diseased plants while others used chemical management which is not an effective management strategy for bacterial pathogens. The lack of action by the farmers who observed the disease is bad but when farmers do not dispose uprooted plants well and safely, it is not much better. There is need for a concerted effort to raise awareness about these diseases and also promote efficient and actionable management strategies. This could be possible with mobile SMS and through extension which were overwhelmingly selected as the most preferred information dissemination methods.

With the exception of *C. sepedonicus*, SRP species were identified both in plants and soils. *Dickeya* species were identified in tubers collected from two farm in Elgeyo Marakwet and Narok counties. This was the first record of this species in Kenya. *Pectobacterium* species such as *P. brasiliense*, *P. carotovorum* and *P. parmentieri* originally reported by Kamau et. al. (17) in Kenya were also detected. *P. parmentieri* was also reported in Kenya by Kamua and asscoaiates (17) but was not tested in this study. In addition, *P. atrosepticum* was detected in samples collected from all six counties. Like *Dickeya* species, this was the first detection of this species in Kenya. Multiple species (*Dickeya* and *Pectobacterium*) were reported from the same field as well as the same sample. This has been reported before in tubers which have been shown to be contaminated with more than one bacterial pathogens (47). This observation and reports by Pérombelon (47) supported the decision of processing and isolating from samples especially stems received in duplicate, triplicate or quadruplicate from the same farm. The isolation of similar subspecies from soil and plants obtained from the same farm also underscores a possible soil-borne transmission. Transmission of bacterial pathogens from soil to plants has been documented in many plant/pathogen interactions, *R. solanacearum* which also affects potato, being the best example (109–111). One in every 10 samples tested positive for SRP, an indication of a high prevalence of the blackleg and soft rots in the smallholder potato production systems in Kenya. The over-reliance on the informal sector for potato seed could be blamed for poor quality potato as reported by processing companies and the low yields observed across the value chain. Muthoni et al. (8) and Kinyua et al. (7) have reported this before and blamed it for the spread of seed-borne pathogens especially *R. solanacearum* and probably now *Dickeya* and *Pectobacterium* species (112). From some of the farms, *Pectobacterium* species were detected in the soil and in the plants possibly pointing to spread from soil to plants.

7.3 Conclusion

A number of conclusion can be drawn from this study;

(i) The majority of farmers relied mainly on the informal seed sector for potato seed.

(ii) Interviewed farmers claimed to have a good understanding of potato production and management. This contracts earlier studies.

(iii) Irrigation is not widely used.

(iv) Contrary to earlier studies, there is a good understanding of management of key potato pests (especially *A. solani*, *P. infestans*, *R. solanacearum*, aphids, cutworms, whiteflies) amongst smallholder potato farmers.

(v) There is less knowledge about the target pests (*C. sepedonicus*, *Dickeya* and *Pectobacterium* species) amongst smallholder potato farmers.

(vi) *C. sepedonicus*, the cause of bacterial ring rot disease in potato was not identified in any of the samples tested.

(vii) Soft rot *Pectobacteriacea* were found to be widespread and they were identified in one of every ten samples tested;

- *Dickeya* and *Pectobacterium* species can occur in the same field and plant and were therefore also found in the same sample in a number of cases. *Dickeya* species was identified for the first time in Kenya on two farms, each in a different county.
- *P. brasiliense*, *P. carotovorum*, and *P. parmentieri* which have been reported in Kenya previously, were again frequently detected.
- *P. atrosepticum* which has not been reported before in Kenya was identified in samples tested across all counties surveyed and therefore, found to be also more established than expected.
- The genus *Dickeya* has not been reported in Kenya before however, it was identified in samples collected in Elgeyo Marakwet and Narok counties and one of the samples identified as *D, solani* and in Taita Taveta county by KALRO and identified as *D. solani* and *D. dianthicola*.

7.4 Recommendations

The project has demonstrated a few issues that need to be addressed. For instance; there is high dependence on the informal seed system for potato seed supply; and blackleg and soft rot causing bacteria are present in both tubers and soil. The following is suggested;

(i) Develop fit-for-purpose information and communication materials in the form of Pest Management Decision Guides (PMDG)s, illustrative factsheets and photo guides suited to different stakeholders (farmers, extension, research, academia, and agro-input suppliers) to support awareness raising.

(ii) Raise awareness on prevention and control measures regarding bacterial pest problems (brown rot, blackleg and soft rots). It is recommended to compare

awareness options and develop and roll out the most effective awareness strategy. This could be achieved through Mass Extension Campaigns (MECs) using radio, plant health rallies and mobile SMS. The messages may include amongst others, the following;

- Applying a minimum of a 1 to 3 rotation;
- Removing volunteer plants and wild hosts as much as possible by proper weed control; Not to cut seed to be planted for seed production;
- Discouraging cutting seed for ware potato production, and if done, disinfecting the implement in Sodium Hypoclorite (5%) (house bleach); Taking hygienic measures, like disinfection of implements/boots with household bleach;
- Rogueing and proper destruction of pest-infested plants as from early in the season (starting as early as you can see symptoms); Controling insects when appropriate;
- Careful harvesting under dry conditions and storage where possible under cooled conditions;
- Not to use pesticides to combat the target pathogens as they are ineffective against bacterial pathogens.

(iii) Train extension officers on field identification of blackleg and soft rots as well as sampling and hygiene, and appropriate actionable management strategies.

(iv) Develop, adapt or repurpose protocol for detection of *Dickeya* and *Pectobacterium* species in tubers, minitubers, and micro-propagated plants.

(v) Extend sampling and testing during active growth to facilitate seed certification to include *Dickeya* and *Pectobacterium* species.

(vi) Routine surveillance of *C. sepedonicus* to update its status in the country may be considered.

(vii) Discuss in a multi-stakeholder setting the feasibility, advantages and disadvantages of delineating Pest Free Areas (PFAs) for the production of certified seed or at least for the production of the early generations of seed multiplication. Explore the potential of production and multiplication of pest-free potato seed in non-traditional potato growing areas.

(viii) Support interventions that increase availability of certified seed potato.

This surveillance demonstrated that lack of certified seed potato is one of the causes of the widespread occurrence of the target pathogens. This is in line with previous reports from many studies conducted in Kenya. One of the key issues that was identified through problem analysis as indicated in Figure 1.4 was the poor distribution network. This has two effects; i) high prices; and 2) low usage of certified seed potato. Any intervention that is aimed at improving the distribution network and also make certified seed affordable, will increase usage of certified seed especially under smallholder potato production systems. However, this will only be possible if the causes of low availability of certified seed potato as indicated in Figure 1.4 are also addressed. There is need to support and subsidise certified seed growers to increase distribution and also lower the prices. This could be through incentives for producing certified seed such as differential pricing or policy.

(ix) Support smallholder potato farmers to produce better quality planting materials on-farm

The social-economic study demonstrated that smallholder potato farmers heavily depend on seed from the informal sector especially own seed (home-saved), obtain seed from fellow farmers or seed bought from the market. This has resulted in transmission of seed-borne pests. The causal pathogens such as *R. solanacearum* and PCN have ended-up infesting the soils too. It is therefore important that KEPHIS works with extension and other development partners to support farmers with methods that can enable them maintain pest-free potato seed for own-use. The common methods promoted are;

(a) Positive Selection

Train farmers in positive selection. In positive selection, farmers select and mark healthy-looking plants as mother plants to produce better quality seed potato. This method that has been previously promoted for use by smallholder potato farmers in East Africa (113).

(b) Seed Plot Technique

Train farmers in the seed plot technique. In the seed plot technique, farmers use seed plots to improve the quality of their saved seed. Initial tubers have to be of exceptional quality, preferably certified. This technique provides a platform for obtaining seed free from tuber-borne pathogens such as *R. solanacearum* which has always been the target but also *Dickeya* and *Pectobacterium* species. This method has also been promoted previously among smallholder potato farmers in East Africa (114).

(x) Screening for tolerant varieties

According to the Potato Variety Catalogue for 2019, there over 60 potato varieties in Kenya. Pests to which this varieties have been reported to display tolerance include *A. solani*, *P. infestans*, *R. solanacearum*, *Rhizoctonia solani* (cause of black scurf), *Streptomyces scabies* (cause of common scab) and *Spongospora subterranea* (cause of powdery scab), *Synchytrium endobioticum* (cause of potato wart disease), *G. rostochiensis*, PVY (strains N and NTN), and PVX. Only Destiny and Jelly have been reported to display tolerance to SRP and are presented as *Erwinia* spp. (Destiny) and blackleg (Jelly). Efforts should be made to evaluate tolerance of all varieties to SRP. This is better achieved through a multi-stakeholder initiative of key value chain actors.

(xi) Review quarantine status of Soft Rot *Pectobacteriaceae* (SRP)

This project including the additional surveillance conducted in Elgeyo Marakwet and Narok (Appendix I) and the surveillance conducted in Taita Taveta by KALRO (Appendix J) presents evidence of presence of additional SRP in addition to those originally reported by Kamau et al. (17) which have also been reported in this study. Therefore, it is necessary to review the quarantine status of SRP whose presence has been reported. *Pectobacterium* is made up of 18 species (Section 2.2.1) of which 4 are present in Kenya while *Dickeya* is made up of 12 (Section 2.2.2) of which 2 could be present *D. solani* and *D. dianthicola* (Appendix I and J).

Funds permitting, it will be important to determine the status of other SRP species in country.

(xii) Seed certification

KEPHIS has a clear seed certification process which may need reviewing to address the current state of some SRP in the country.

(xiii) Pest Risk Analysis (PRA)

It is important pest-initiated PRAs are conducted for *P. atrosepticum*, *D. solani*, and *D. dianticola*. This is will help decide the most appropriate actions that will reduce the risk of damage these pests may have on plants and plant products. The PRAs may be extended to other species of SRP that may be deemed high risk to the potato and other value chains.

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Appendices

A

Questionnaire

Information as presented in the Open Data Kit (ODK) tool

Agree to participate: *Yes/No*

GENERAL INFORMATION

1	Provide your name (enumerator)
2	Date of the data collection exercise
3	Select the county: *From drop-down list*
4	Select the sub county: *From drop-down list*
5	Select the ward: *From drop-down list*
6	Record the name of the respondent
7	Select farmer's sex: Female/Male *Interviewer observation. Do not ask*
8	Select farmer's age category: *From drop-down list* <30 years; 31 to 35; 36 to 45; 46 to 55; >55 years

CROPS CULTIVATED

9a	Select the most important crop cultivated: *From drop-down list*
9a(i)	If other, please specify
9a(ii)	What is the acreage under the crop?
9a(iii)	What is the KEY purpose of the crop to the household? *Select from choices* Subsistence (food); Income; Both (subsistence and income source)
9b	Select the second most important crop cultivated: *From drop-down list*
9b(i)	If other, please specify
9b(ii)	What is the acreage under the second crop?
9b(iii)	What is the KEY purpose of the second crop to the household? *Select from choices* Subsistence (food); Income; Both (subsistence and income source)

9c	Select the third most important crop cultivated: *From drop-down list*
9c(i)	If other, please specify
9c(ii)	What is the acreage under the third crop?
9c(iii)	What is the KEY purpose of the third crop to the household? *Select from choices* Subsistence (food); Income; Both (subsistence and income source)
10a	Select the first potato variety cultivated: *From drop-down list*
10a(i)	If other, please specify
10a(ii)	What is the acreage under the first variety?
10b	Select the second potato variety cultivated: *From drop-down list*
10b(i)	If other, please specify
10b(ii)	What is the acreage under the second variety?
10c	Select the third potato variety cultivated: *From drop-down list*
10c(i)	If other, please specify
10c(ii)	What is the acreage under the third variety?
11	Where did you obtain the seed you planted in the potato field?
11(i)	If other, please specify
12	Briefly describe your cropping history

AGRONOMIC PRACTICES

13	Did you apply any of the following agronomic practices on your potato crop? *Yes/No*
13a	Planted improved seed
13b	Used recommended spacing
13c	Fertilizer application
13d	Scouting for pest and diseases
13e	Crop rotation
13f	Weeding
13g	Pest and disease control
13h	Mulching
13i	Irrigation
13j	Intercropping
14a	Which crops did you rotate your potato crop with? *From drop-down list*
14a(i)	If other, please specify
14b	Which pests and diseases did you control? *From drop-down list*
14b(i)	If other, please specify
14c	Which method of irrigation did you use? *From drop-down list*
14c(i)	If other, please specify

INFORMATION SOURCES

15	Did you utilise any of the following sources of information on the agronomic practices put in place to improve potato production in your farm?
15a	Own experience
15b	Demonstration plots/ field days/Farmer Field Schools (FFSs)
15c	Neighbours, family and friends
15d	Farmer cooperative
15e	Lead farmer or village-based advisor
15f	Mobile SMS
15g	Agricultural program on radio/TV
15h	Government extension officer
15i	Magazine, newspaper, leaflets
15j	Agro-dealer
15k	CABI Plant doctor

BLACKLEG DISEASE

16a	Have you ever seen this disease on your or the neighbour's farm? *Enumerator displays photos showing blackleg disease*
16b	What did you do when you saw the disease?
16c	Select the potato varieties affected by blackleg and from which samples have been collected: *From drop-down list*
16c(i)	If other, please specify.
16d	What is the development stage of the potato varieties affected by blackleg, from which samples have been collected?
17	Select the unit used to measure area affected by the disease.
18	How much area of the farm are affected by the disease?
19	Record the percentage of plants affected by the disease.
20	What is the spatial pattern of plants damaged by the disease?

SOFTROT DISEASE

21a	Have you ever seen this disease on your or the neighbour's farm? *Enumerator displays photos showing softrot damage*
21b	What did you do when you saw this disease?
21c	Select the potato varieties affected by soft rot disease and from which samples have been collected.
21c(i)	If other, please specify.
21d	What is the development stage of the potato varieties affected by soft rot, from which samples have been collected?
22	Select the unit used to measure area affected by the disease.
23	How much area of the farm are affected by the disease?
24	Record the percentage of plants affected by the disease.
25	What is the spatial pattern of plants damaged by the disease?

RING ROT DISEASE

21a	Have you ever seen this disease on your or the neighbour's farm?
	Enumerator displays photos showing ringrot disease
21b	What did you do when you saw this disease?
21c	Select the potato varieties affected by this disease and from which samples have they been collected.
21c(i)	If other, please specify.
21d	What is the development stage of the potato varieties affected by ringrot, from which samples have been collected?
22	Select the unit used to measure the area affected by the disease.
23	How much area of the farm are affected by the disease?
24	Record the percentage of plants affected by the disease.
25	What is the spatial pattern of plants damaged by the disease?

INFORMATION DISSEMINATION

26a	In case there is an outbreak of these diseases, name the first method you like the information to be disseminated to farmers in your county
26b	In case there is an outbreak of these diseases, name the second method you like the information to be disseminated to farmers in your county?
26c	In case there is an outbreak of these diseases, name the third method you like the information to be disseminated to farmers in your county?
27	If I needed to contact you for clarification or information, what is the phone number I could use?
28	Take GPS coordinates of the farm
29	Record the sample number

B

Buffer and Stock Solutions

Buffers and stock solutions adopted from Humphris et al. (115)[6]; Pérombelon and van Der Wolf, (58)[7] and Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8]

B.1 0.5 M EDTA pH 8.0

- Weigh EDTA ($C_{10}H_{16}N_2O_8$) (Sigma-Aldrich) 186.12 g
- Dissolve in 800 mL sterile distilled water
- Add about 20 g of Sodium hydroxide (NaOH) pellets (Sigma-Aldrich)[9]
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121 ^{o}C for 15 min.

B.2 Dithiothreitol (1 M)

- Weigh Dithiothreitol (DTT) (Sigma-Aldrich) 1.54 g
- Dissolve in 10 mL sterile distilled water.
- Prewet a 0.22 μm syringe filter by drawing through 10 mL of sterile water.
- Discard water
- Sterilize DTT stock through the prepared 0.22 μm syringe filter.
- Aliquot into 2 mL tubes and store at -20^{o}C.
- Keep stocks for up to one year.

B.3 Sodium Acetate (3 M)

- Weigh Sodium acetate (CH_3COONa) (Sigma-Aldrich) 204.05 g
- Dissolve in 800 mL water.
- Adjust pH to 5.2 with Glacial acetic acid (CH_3COOH) (Sigma-Aldrich)
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 15 min.

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[8] https://www.aphis.usda.gov/plant_health/plant_pest_info/potato/downloads/dickeya/npc-dickeya-protocol.pdf

[9] EDTA will not dissolve until the pH is near 8.0. Therefore, slowly add more Sodium hydroxide until pH is 8.0.

B.4 Sodium Chloride (5 M)

- Weigh Sodium chloride (NaCl) (Sigma-Aldrich) 292.2 g
- Dissolve in 800 mL distilled water.
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 15 min.

B.5 Sodium Hydroxide (10 M)

- Weigh Sodium hydroxide (NaOH) (Sigma-Aldrich) 40.0 g
- Dissolve in 50 mL distilled water.
- Bring volume up to 100 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 15 min.

B.6 Proteinase K (2 mg/mL)

- Weigh Proteinase K (Sigma-Aldrich) 20.0 mg
- Dissolve in mL sterile distilled water and store at -20^{o}C.

B.7 1 M Tris, pH 8.0

- Weigh Tris base ($C_4H_{11}NO_3$) (Sigma-Aldrich) 121.1 g
- Dissolve 800 mL sterile distilled water.
- Adjust pH to 8.0 with concentrated Hydrochloric acid (HCl) (Sigma-Aldrich).
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 15 min.

B.8 CTAB Buffer

- Tris base (Sigma-Aldrich) (1 M, pH 8.0) 100 mL
- Sodium chloride (Sigma-Aldrich) (5 M) 280 mL
- EDTA (Sigma-Aldrich) (0.5 M, pH 8.0) 40 mL
- CTAB (Sigma-Aldrich) 20.0 g
- Bring volume up to 1000 mL with sterile distilled water

B.9 CTAB Extraction Buffer

- CTAB buffer 20 mL
- PVP ($(C_6H_9NO)_n$) (Sigma-Aldrich) 0.8 g
- β-Mercaptoethanol (C_2H_6OS)[10] (Sigma-Aldrich) 100 μL
- Put the solution in the water bath for 10-20 min to dissolve the PVP.
- Avoid shaking the solution to stop the detergent from bubbling.
- Add β-Mercaptoethanol just before use

[10] Use fume cabinet - fumes of β-Mercaptoethanol are poisonous!

B.10 10 mM Phosphate Buffer

- For resuspension and dilution of potato tuber heel-end core extracts following concentration to a pellet by centrifugation[6,7].
- Dissolve the following components in 800 mL distilled water;
  - Sodium phosphate dibasic dodecahydrate ($Na_2HPO_4 \cdot 12H_2O$) (Sigma-Aldrich) 2.7 g
  - Sodium phosphate monobasic dihydrate ($NaH_2PO_4 \cdot 2H_2O$) (Sigma-Aldrich) 0.4 g
  - Adjust pH to 7.2
  - Bring volume up to 1000 mL with distilled water.
  - Sterilize by autoclaving at 121^{o}C for 15 min.

B.11 50 mM Phosphate Buffer

- For extraction of the bacteria from plant tissues by homogenization or shaking[6,7].
- Dissolve the following components in 800 mL distilled water;
  - Di-sodium hydrogen phosphate (Na_2HPO_4) (Sigma-Aldrich) 4.26 g
  - Potassium dihydrogen phosphate (Sigma-Aldrich) 2.72 g
  - Adjust pH to 7.0
  - Bring volume up to 1000 mL with distilled water.
  - Sterilize by autoclaving at 121^{o}C for 15 min.

B.12 Ringer's Buffer

Adopted from the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8]

- Sodium chloride (Sigma-Aldrich) 2.25 g
- Potassium chloride (KCl) (Sigma-Aldrich) 0.12 g
- Sodium bicarbonate ($NaHCO_3$) (Sigma-Aldrich) 0.05 g
- Calcium chloride hexahydrate ($CaCl_2.6H_2O$) (Sigma-Aldrich) 0.12 g
- Adjust pH to 7.0
- Sterilize by autoclaving at 121^{o}C for 15 min.

B.13 Freezing Medium

Adopted from Pérombelon and van Der Wolf, (58)[7].

- In 800 mL distilled water, dissolve the following components;
  - Di-potassium phosphate (Sigma-Aldrich) 12.6 g
  - Potassium dihydrogen phosphate (KH_2PO_4) (Sigma-Aldrich) 3.6 g
  - Sodium citrate ($Na_3C_6H_5O_7$) (Sigma-Aldrich) 0.9 g
  - Magnesium sulphate ($MgSO_4$) (Sigma-Aldrich) 0.18 g
  - Ammonium sulphate (Sigma-Aldrich) 0.18 g
  - Glycerol (Sigma-Aldrich) 88.0 g
- Bring volume up to 1000 mL with Sterile distilled water.
- Sterilize by autoclaving at 121^{o}C for 15 min.

B.14 Double Strength Pectate Enrichment Medium (D-PEM)

Adopted from Humphris et al. (115)[6], Pérombelon and van Der Wolf, (58)[7] and the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8].

- Dissolve the following components in order of the recipe in 300 mL distilled water and heat if necessary;
  - Magnesium sulphate ($MgSO_4$) (Sigma-Aldrich) 0.64 g
  - Ammonium sulphate ($(NH_4)_2SO_4$) (Sigma-Aldrich) 2.16 g
  - Di-potassium phosphate (K_2HPO_4) (Sigma-Aldrich) 2.16 g
- Bring volume up to 1000 mL with distilled water.
- Suspend 3.4 g of the Sodium polypectate ($C_{18}H_{23}NaO_{19}{}^{-2}$) (Sigma-Aldrich) in 5 mL of absolute Ethanol and add to the salts solution, mixing well using a magnetic stirrer.
- Steam until the polypectate is completely dissolved.
- Adjust pH to 7.2, if necessary.
- Prepare small aliquots (e.g. 50 mL)
- Sterilise by autoclaving at 121^{o}C for 15 min.
- Store and store at 4^{o}C.
- Once open, do not re-use to avoid contamination.

B.15 Single Strength Pectate Enrichment Medium (D-PEM)

Adopted from Humphris et al. (115)[6], Pérombelon and van Der Wolf, (58)[7] and the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8].

- Similar procedure as for D-PEM except that the concentrations are halved.

B.16 TE Buffer

- Tris (1 M, pH 8.0) (Sigma-Aldrich) 10.0 mL
- EDTA (0.5 M, pH 8.0) 2.0 mL
- Bring volume up to 1000 mL with sterile distilled water
- Sterilize by autoclaving at 121^{o}C for 15 min.

B.17 10X TAE Electrophoresis Buffer

- Tris (1 M, pH 8.0) (Sigma-Aldrich) 48.4 g
- Glacial Acetic acid (Sigma-Aldrich) 11.4 mL
- EDTA (0.5 M, pH 8.0) (Sigma-Aldrich) 20.0 mL
- Bring volume up to 1000 mL with sterile distilled water
- Store at room temperature
- Dilute stock solution 10:1 to make a 1X working solution[11]

[11] 1X buffer contains 40 mM Tris, 20 mM Glacial acetic acid and 1 mM EDTA

C

Media

C.1 Double-layer CVP (DL-CVP) Medium

Adopted from Humphris et al. (115)[6], Pérombelon and van Der Wolf, (58)[7] and the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8].

- Add each ingredient in the order listed and dissolve each ingredient slowly before adding the subsequent one on the list.
- Dissolved the following components in 800 mL of distilled water (Basal layer);
  - Calcium chloride dihydrate ($CaCl_2.2H_2O$) (Sigma-Aldrich) 5.5 g
  - Tryptone (Sigma-Aldrich) 1.0 g
  - Sodium nitrate ($NaNO_3$) (Sigma-Aldrich) 1.6 g
  - Crystal Violet (0.1% Aqueous solution) (Sigma-Aldrich) 1.5 mL
  - Agar (Oxoid) 15.0 g
  - Bring volume up to 1000 mL with distilled water
- Dissolved the following components in 600 mL of distilled water (Top layer);
  - EDTA (5.5%, pH 8.0) (Sigma-Aldrich) 2.0 mL
  - Sodium hydroxide (5 M) (Sigma-Aldrich) 4.8 mL
  - Sodium polypectate (Sigma-Aldrich) 20.0 g
  - Add the polypectate slowly and heat the solution to 80-100^{o}C while stirring with a magnetic stirrer to near full speed to avoid lump formation.
  - Adjust pH to 7.0.
  - Bring volume up to 800 mL with distilled water
- Autoclave the two solutions for 15 min at 120^{o}C.
- Restore pressure slowly to avoid bubble formation within the medium.
- Cool the media for basal layer to 45-50^{o}C and pour into Petri dishes (approximately 15 mL per dish in 9-cm petri dishes).
- Allow the basal layer to set in a laminar flow hood to remove excess surface moisture.
- Then pour the top layer (approximately 7 mL per dish in 9 cm petri dishes).
- Place plates with lids ajar for 1 h in a biosafety hood or laminar flow at room temperature for 1-4 h to eliminate all surface condensation.
- If CVP medium is to be used straight away, chill plates for at least 2 h at 4^{o}C after pouring.
- Store plates at 4^{o}C for up 2 months in a sealed polythene bag.
- CVP medium will be grey when properly prepared.
- Double layer is more time consuming and difficult to make, but can be more suited to samples with large numbers of bacteria due to its slower cavity development.

C.2 Single-layer CVP (SL-CVP) Medium

Adopted from Humphris et al. (115)[6], Pérombelon and van Der Wolf, (58)[7] and the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8].

- Add each ingredient in the order listed and dissolve each ingredient slowly before adding the subsequent one on the list.
- Dissolved the following components in 400 mL of distilled water (Mix A)
  - Calcium chloride dihydrate (Sigma-Aldrich) 1.02 g
  - Tryptone (Sigma-Aldrich) 1.0 g
  - Sodium citrate ($Na_3C_6H_5O_7$)[12] (Sigma-Aldrich) 5.0 g
  - Sodium nitrate (Sigma-Aldrich) 2.0 g
  - Crystal Violet (0.1% Aqueous solution)[13] (Sigma-Aldrich) 1.5 mL
  - Agar (Oxoid) 4.0 g
  - Dissolve Mix A ingredients in water using a magnetic stirrer.
  - Adjust pH to 7.0.
  - Bring volume up to 500 mL with distilled water
- Dissolved the following components in 400 mL of distilled water (Mix B)
  - Sodium hydroxide (5 M) (Sigma-Aldrich) 2.8 mL
  - Sodium polypectate (Sigma-Aldrich) 18.0 g
  - Add Sodium hydroxide (Sigma-Aldrich) first to 500 mL of distilled water followed by polypectate.
  - Add the polypectate slowly and heat the solution to 80-100^{o}C while stirring with a magnetic stirrer to near full speed to avoid lump formation.
  - Adjust pH to 7.0
  - Bring volume up to 500 mL with distilled water
- Autoclave both Mix A and Mix B separately for 15 min at 120^{o}C.
- Restore pressure slowly to avoid bubble formation within the medium.
- Carefully pour Mix A into Mix B while the solutions are still hot.
- Swirl to mix the solutions together.
- Pour immediately about 18 mL per 9-cm petri dish as the medium cannot be readily re-melted.
- Place plates with lids ajar in a biosafety hood or laminar flow at room temperature for 1-4 h to eliminate all surface condensation.
- If CVP medium is to be used straight away, chill plates for at least 2 h at 4^{o}C after pouring.
- Store plates at 4^{o}C for up 2 months in a sealed polythene bag.
- CVP[14] medium will be grey when properly prepared.

C.3 Luria Bertani Agar (LBA)

Adopted from Pérombelon and van Der Wolf, (58)[7].

- Dissolved the following components in 800 mL of distilled water;
  - Bacto peptone (Oxoid) 10.0 g
  - Yeast extract (Oxoid) 5.0 g
  - Sodium chloride (Sigma-Aldrich) 10.0 g
  - Agar (Oxoid) 15.0 g
- Adjust pH to 7.5.
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 20 min.

C.4 Luria Broth (LB)

Adopted from Pérombelon and van Der Wolf, (58)[7].

- As LBA but without the agar

[12] Sodium citrate reduces growth and pit formation by pectolytic *Pseudomonas* species.

[13] Store Crystal violet stock solutions at 4^{o}C

[14] The final pH of CVP should be 6.9-7.2. If necessary, adjust by adding Sodium hydroxide before pouring. It is easier to raise than to lower the pH in this medium.

C.5 MTNA Medium

Adopted from EPPO (31)[15]

- Dissolved the following components in 800 mL of distilled water;
  - Yeast extract (Oxoid) 2.00 g
  - D-Mannitol (Sigma-Aldrich) 2.50 g
  - Di-potassium phosphate (K_2HPO_4) (Sigma-Aldrich) 0.25 g
  - Potassium dihydrogen phosphate (KH_2PO_4) (Sigma-Aldrich) 0.25 g
  - Sodium chloride 0.05 g
  - Magnesium sulphate heptahydrate ($MgSO_4 \cdot 7H_2O$) (Sigma-Aldrich) 0.10 g
  - Manganese sulphate monohydrate ($MnSO_4 \cdot H_2O$) (Sigma-Aldrich) 0.015 g
  - Ferrous sulphate heptahydrate ($FeSO_4 \cdot 7H_2O$) (Sigma-Aldrich) 0.005 g
  - Agar (Oxoid) 16.00 g
- Adjust pH to 7.2 with Concentrated Hydrochloric acid (HCl).
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 15 min.
- Add the following antibiotics after filter-sterilizing;
  - Trimethoprim 0.060 g
  - Nalidixic acid 0.002 g
  - Amphotericin B 0.010 g.
- All antibiotics where from Sigma-Aldrich
- Antibiotic stock solutions should be kept in 96% Ethanol (Trimethoprim and Nalidixic acid) and DMSO ($(CH_3)_2SO$) for Amphotericin B1. Stock solutions should be filter-sterilized.
- Durability of basal medium is 3 months. After antibiotics are added durability is 1 month when media is stored at 4^{o}C.

C.6 NCP-88 Medium

Adopted from EPPO (31)[15].

- Dissolved the following components in 800 mL of distilled water;
  - Nutrient agar (Oxoid) 23.0 g
  - Yeast extract (Oxoid) 2.0 g
  - D-Mannitol (Sigma-Aldrich) 5.0 g
  - Di-potassium phosphate (Sigma-Aldrich) 2.0 g
  - Potassium dihydrogen phosphate (Sigma-Aldrich) 0.5 g
  - Magnesium sulphate heptahydrate (Sigma-Aldrich) 0.25 g
- Adjust pH to 7.2.
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 15 min and cool down to 50^{o}C.
- Add the following antibiotics after filter-sterilizing;
  - Polymyxin B sulphate 0.003 g
  - Nalidixic acid 0.008 g
  - Cycloheximide 0.200 g.
- All antibiotics where from Sigma-Aldrich
- Antibiotic stock solutions should be kept in 50% Ethanol (Cycloheximide) and sterile distilled water (Polymyxin B). Stock solutions should be filter-sterilized.
- Durability of basal medium is 3 months. After antibiotics are added durability is 1 month when media is stored at 4^{o}C.

[15] EPPO, 2006, *Clavibacter michiganensis* subsp. *sepedonicus*: Diagnostics, Bulletin OEPP/EPPO Bulletin 36, Pages 99–109. https://gd.eppo.int/download/standard/183/pm7-059-1-en.pdf

C.7 Nutrient Agar (NA)

Adopted from Pérombelon and van Der Wolf, (58)[7].

- Dissolved the following components in 800 mL of distilled water;
  - Lab Lemco (Oxoid) 1.0 g
  - Yeast extract (Oxoid) 2.0 g
  - Bacto peptone (Oxoid) 5.0 g
  - Sodium chloride (Sigma-Aldrich) 5.0 g
  - Agar (Oxoid) 15.0 g
- Adjust pH to 7.0.
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving at 121^{o}C for 20 min.

C.8 Nutrient Broth (NB)

Adopted from Pérombelon and van Der Wolf, (58)[7].

- As NA but without the agar.

C.9 Yeast extract Glucose Mineral (YGM) Medium

Adopted from EPPO (31)[15].

- Dissolved the following components in 800 mL of distilled water;
  - Bacto Yeast extract (Oxoid) 2.00 g
  - D(+) Glucose (monohydrate) (Sigma-Aldrich) 2.50 g
  - Di-potassium phosphate (Sigma-Aldrich) 0.25 g
  - Potassium dihydrogen phosphate (Sigma-Aldrich) 0.25 g
  - Sodium chloride (Sigma-Aldrich) 0.050 g
  - Magnesium sulphate heptahydrate (Sigma-Aldrich) 0.10 g
  - Manganese sulphate monohydrate (Sigma-Aldrich) 0.015 g
  - Ferrous sulphate heptahydrate (Sigma-Aldrich) 0.005 g
  - Agar (Oxoid) 18.00 g
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving 0.5 L volumes of medium at 121^{o}C for 20 min and cool down to 50^{o}C.

C.10 YGM-modified Medium

Adopted from EPPO (31)[15].

- Dissolved the following components in 800 mL of distilled water;
  - Yeast extract (Oxoid) 2.00 g
  - Di-potassium phosphate (Sigma-Aldrich) 0.25 g
  - Potassium dihydrogen phosphate (Sigma-Aldrich) 0.25 g
  - Magnesium sulphate heptahydrate (Sigma-Aldrich) 0.10 g
  - Manganese sulphate monohydrate (Sigma-Aldrich) 0.15 g
  - Sodium chloride (Sigma-Aldrich) 0.05 g
  - Ferrous sulphate heptahydrate (Sigma-Aldrich) 0.005 g
  - Bromothymol blue (Sigma-Aldrich) 0.05 g
  - Agar (Oxoid) 18.00 g
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving 0.5 L volumes of medium at 121^{o}C for 20 min and cool down to 50^{o}C.

C.11 Nutrient Broth Yeast extract (NBY) Medium

Adopted from EPPO (31)[15].

- Dissolved the following components in 800 mL of distilled water;
  - Nutrient agar (Oxoid) 23.00 g
  - Yeast extract (Oxoid) 2.00 g
  - Potassium dihydrogen phosphate (Sigma-Aldrich) 0.50 g
  - Di-potassium phosphate (Sigma-Aldrich) 2.00 g
  - Magnesium sulphate heptahydrate (Sigma-Aldrich) 0.25 g
  - D-Mannitol (Sigma-Aldrich) 5.00 g
  - Agar (Sigma-Aldrich) 18.00 g
- Bring volume up to 1000 mL with distilled water.
- Sterilize by autoclaving 0.5 L volumes of medium at 121^{o}C for 20 min, cooling to 50^{o}C.

D

Sample collection and processing

Adopted from the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8].

Ship samples[16] in insulated containers to protect them from temperature extremes during shipment.

D.1 Symptomatic Samples

- Collect symptomatic samples[17] (tubers or stems) individually from different lots/locations.
- Place in separate labeled Khaki paper bags to avoid cross contamination.
- Micropropagated plants can be shipped in the vessel used to grow the plant.
- To reduce shipping components, a 2-3 inch stem section that contains the intersection between diseased and healthy stem tissue (edge of lesions) can be collected.
- Decontaminate hands and tools between samples if tools are used during collection.
- Ship samples overnight.

D.2 Asymptomatic Samples

- For seed lot screening, collect random tuber or stem samples.
    - It is recommended to collect at least 200 tuber samples from a single seed lot. Larger sample sizes will enable detection of lower incidences in the seed lots. Collecting 400 tuber samples, provides a 95% confidence especially if pathogen incidence is less than 1% or if no pathogen is found during testing.
    - The stem ends of tubers can be sliced off and shipped for processing to save on shipping costs and decrease processing time. Be sure to include tuber periderm in samples on the stem ends.
    - Healthy-appearing tuber samples collected from a single seed lot do not need to be separated from each other.
- For stems, collect approximately 2-3 inch sections of stems at ground level. If *Dickeya* or *Pectobacterium* are present they will be at the highest concentration at this location.
- Micropropagated plants can be shipped in the container in which they are grown.

[16] Tubers, minitubers, stems, or micropropagated plants

[17] If more than one stem or tuber has been collected, all tubers or stems can be combined to make one sample. Both *Dickeya* and *Pectobacterium* species can be found in the same field hence processing samples individually provides some information on which pathogen is more prevalent.

E

Isolation of *Clavibacter sepedonicus*

Excepts of the protocol adopted from EPPO (31)[15].

E.1 Symptomatic materials

- Wash the test (tubers, stems or leaves) samples in running water to remove excess soil.
- Sterilize the surface with 0.5 % Sodium hypochlorite or 70 % Ethanol for 5 min.
- Remove ooze or sections of discoloured tissue from the vascular ring in tubers or from the vascular strands of stems or leaves.
- Crush the material in a small volume of sterile distilled water or 50 mM Phosphate buffer and leave for 5-10 min.
- Prepare a series of decimal dilutions of the suspension in 10 mM Phosphate buffer. This is important because the bacterium is usually present in high populations in infected tissues; the saprophytes are diluted out remain with the pathogen.
- Spread 100 μL from each sample at 1 in 100 up to 1 in 10000 dilutions, onto MTNA or NCP-88 medium with spreaders.
- Alternatively, spread out the initial 100 μL potato aliquot onto first agar plate with a spreader. The spreader is then used on a second agar plate, streaking out any left residue and lastly on a third plate. This gives a dilution plating effect via the spreader.
- Incubate the plates in the dark at 21-23 ^{o}C.
- After 3 days, examine the plates by comparing with positive controls. Repeat this after 5, 7 and possibly 10 days.
- Purify presumptive colonies on YGM preferably after 3-5 days before the plates become too overgrown.
- Use purified cultures for identification.

E.2 Asymptomatic Materials and Screening for Latent Infections

- Use a sample of at least 200 tubers.
- Larger number of tubers in the sample will lead to inhibition or generate difficult results to interpret.
- The procedure can also be conveniently applied for samples with less than 200 tubers.

F

Isolation of Soft Rot *Pectobacteriaceae*

F.1 Background

Isolation of the SRP, *Pectobacterium* and *Dickeya* species is made on selective diagnostic CVP medium[18]. They can be isolated from the leaves and stems of potato plants or the peel and stolon end of tubers. In the tubers, the bacteria are normally present in the lenticels, the periderm[19], around the eyes, and in the stem end. They reach a very high concentration in the stem end of the tuber. They may be found at higher incidence but low concentration on tuber periderm. Sampling and processing the peel and stem (stolon) end cores separately indicates whether the bacterial infection is systemic (found in the vascular tissue of the stolon or stem end) or is found externally as lenticel infection in tuber peel. These bacteria form characteristic deep cup-like cavities or round pits (2-3 mm in diameter) on CVP medium which are different from those formed by other pectolytic *Pseudomonads*, which tend to be shallower and wider. Preparation of the test material depends on whether infection is active, then isolation can be made directly, or if latent, then an enrichment[20] step is included prior to isolation. The procedure described below has been adopted from Humphris et al. (115)[6], Pérombelon and van Der Wolf, (58)[7] and the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8].

F.2 Symptomatic Materials

a. Wash the test samples (tubers, stem or leaves) under running tap water to remove excess soil or debris but avoid breaking the skin.
b. Surface sterilize with 0.5% Sodium hypochlorite or 70% Ethanol for 5 min. Then wash with sterile deionized water or sterilized distilled water three times and finally air-dry.
c. Break or cut open the skin (stem) or extract small portions of tuber to remove a small amount of tissue (approx. 0.1 g). This is done at the intersection of the diseased and healthy tissue (edge of lesion) using a sterile scalpel.
d. Change gloves between samples. Samples can also be cut on paper towels, which should be disposed of between samples.
e. If more than one stem or tuber sample has been collected or submitted, all tubers or stems can be combined to make one sample. However, both *Dickeya* and *Pectobacterium* can be found in the same field hence processing samples individually provides some information on which pathogen is more prevalent.
f. Place diseased tissue pieces in a 2 mL centrifuge tube and store at -80^{o}C if DNA isolation will be conducted for direct PCR diagnosis[21].
g. Otherwise, tease or pulverise the tissue in sterile distilled water (approx. 0.2 mL) in a plastic petri dish. Add antioxidants[22] such as Tetrasodium pyrophosphate ($C_5H_{11}NS_2$) (0.1% final concentration) or Dithiothreitol

[18] CVP remains the most preferred diagnostic selective medium for isolation of SRP (74, 106). The selectivity of CVP medium is based on the presence of crystal violet which inhibits growth of most gram-positive bacterial species and polypectate (pectin) as the sole carbon source.
[19] Collect periderm and stem end samples separately from each tuber or sliced off stem end and process with the periderm intact
[20] If pathogen populations are very low, they may need to be enriched above detection levels. Therefore, the test materials are incubated under anaerobic conditions in liquid enrichment containing Sodium polypectate as the sole carbon source (65).
[21] Note, even if multiple species are detected with PCR assays, it may be difficult to isolate multiple species from a sample because the different species may be present in very disparate ratios.
[22] Adding an antioxidant delays bacterial cell death by toxic substances present in extracts

($C_4H_{10}O_2S_2$) (0.75% final concentration) or Diethyldithiocarbamic acid ($C_5H_{11}NS_2$) (5% volume:volume) to water. Leave for about 5 min to allow the bacteria to diffuse out of the tissue [23].

h. Alternatively, put the diseased tissue into a sterile mortar and homogenize in sterile water. Leave to stand for 20 min.
i. Pipette off the extract from the homogenized sample and prepare a dilution series from 10^0 to 10^{-3} or may increase up to 10^{-6} in sterile distilled water. This ensures that background saprophytes are diluted out and only isolated *Pectobacterium* and *Dickeya* colonies are obtained.
j. Spread 100 μL of each dilution for each sample onto duplicate CVP plates previously dried to remove excess surface moisture.
k. Alternatively, streak, with a sterile inoculating needle with a loop at the end, a loop ful of the liquid from Step i. on to a CVP plate previously dried to remove excess surface moisture to obtain isolated colonies. Streaks should be made in four right angle directions, flaming and cooling the loop after each directional streak.
l. You may also inoculate the 100 μL of homogenate in D-PEM and incubate under anaerobic conditions at 23-28^{o}C for 24 h prior to plating onto CVP.
m. Incubate the CVP plates upside down with one plate at 27^{o}C and the other plate at 37^{o}C for 48 h. Although *Pectobacterium* and *Dickeya* spp are both plated onto CVP, they should be incubated at 27^{o}C and 37^{o}C respectively for colony formation. *Pectobacterium* and *Dickeya* spp form characteristic deep cavities in the medium, due to their ability to break down and metabolize pectin. *Dickeya* grows more slowly and has more smaller colonies than *Pectobacterium*, so plates should be evaluated daily and any new pitting colonies should be removed to a new plate. **Some *Pectobacterium* strains produce copious amounts of plant cell wall degrading enzymes and can liquefy CVP plates.** If this occurs, other media, such as NA plus Isopropyl β-D-1-thiogalactopyranoside (IPTG) ($C_{14}H_{15}BrClNO_6$) plus Isopropyl β-D-1-thiogalactopyranoside ($C_9H_{18}O_5S$) or Nutrient Glycerol Manganese (NGM) can be used to attempt another (repeated) isolation.
n. For use as a back-up stock, a 1 mL aliquot of the homogenate can be removed and added to 200 μL of 100 % sterile glycerol and stored at -20^{o}C or -80^{o}C for longer-term storage.
o. A dilution series of approximately 10^{-1} to 10^{-4} Colony-forming units (CFU) mL^{-1} of a positive control for *Pectobacterium* and *Dickeya* spp. should also be prepared.
p. Select well-spaced colonies or cavities per CVP plate and re-streak on to fresh CVP plate.
q. Incubate plates at respective temperatures, 27^{o}C or 37^{o}C.
r. Select colonies (cavities) from **Step p.**, streak each on NA or LBA (See Appendix C) plate on previously dried (free of excess surface moisture) petri dishes.[24]
s. Incubate at 27^{o}C or 37^{o}C for about one week to grow only *Dickeya* and *Pectobacterium* colonies. SRP form round convex creamy-translucent colonies on NA or LBA[25].
t. You may also subculture bacterial colonies from **Step r.** onto NA medium slants and store at room temperature until use.

F.3 Asymptomatic Materials and Screening for Latent Infections

These typically require a culture-based enrichment step to detect *Dickeya* or *Pectobacterium* spp.

1. **Isolation from Stems**
   a. If present[26], SRP will be in high concentrations at the base of the stem. Use a sterile blade to extract approx. 5-8 cm (2-3 inches) section of plant tissue from the base of each stem or just above the ground level.
   b. Sterilize tools (submerge in 95% alcohol and flame excess alcohol) and work surface (wipe down with 70% alcohol between samples). Sterilization could be also be done between batches of tubers but not necessarily in a single batch.
   c. Change gloves between samples. Samples can also be cut on paper towels, which should be disposed of between samples.

[23] We did not add the antioxidant as we could not have them shipped in time. However, added as explained in the Protocol for detection of *Dickeya* and *Pectobacterium* in potato tubers, stems, or irrigation Water[8] for the benefit of others

[24] You may not pick colonies but instead add approx. 1.5 mL of sterile water to each plate and wash to recover all surface growth. Add approx. 1.3 mL to a 1.5-mL eppendorf and keep at -20^{o}C for further use (recover bacteria). Add the remaining approx. 500 μL to another eppendorf for use in molecular diagnostic tests. Also keep at -20^{o}C.

[25] *Dickeya* does not survive well on some agar medium, such as LBA, and it survives poorly on media stored at cool temperatures (4-10^{o}C). On LBA or at cool temperatures, cells die or become non-culturable within a few days. Therefore, isolates should be stored as soon as a pure culture is obtained. Isolates may be stored indefinitely at -80^{o}C by suspending cells in cryovials filled with filter-sterilized 20% vol:vol glycerol or in cryovials containing ceramic beads. It is crucial that vigorous cells are stored, so cells from freshly streaked plates that are incubated for no more than one day should be used for stored cultures.

[26] Present whether in the field, greenhouse grown stems or in micropropagated plants

d. Wash the samples under running tap water to remove excess soil or debris but avoid breaking the skin.
e. Place samples either into separate universal extraction bags, 12 mL sterile tubes or flasks.
f. Add 15 mL of 0.25 (quarter) strength Ringer's buffer containing Tetrasodium pyrophosphate (0.1% final concentration) or Dithiothreitol (0.75% final concentration) or Diethyldithiocarbamic acid (5% volume:volume) antioxidants to each sample[23].
g. Pulverise to give an oatmeal consistency.
h. Leave to stand for 20 min or **soak samples overnight at room temperature to allow the bacteria to stream out of the samples**.
i. Samples may also be placed on a shaker to aid in recovery of bacteria from the samples.
j. Remove the supernatant (approx. 1.5 mL) and dispense into 2 separate sterile 1.5 mL tubes.
k. Remove 100 μL and continue with **Step 5** if interested in obtaining *Dickeya* or *Pectobacterium* isolates.
l. Otherwise, spin both 1.5 mL tubes in a centrifuge at 14,000 rpm for 2-5 min until a pellet forms.
m. Remove the supernatant from both tubes. Not all supernatant needs to be removed as the pellet is delicate.
n. Designate one tube as "Use for PCR" reaction. Note the pellet can be frozen at -80^{o}C and retrieved at a later date for processing.
o. Add 500 μL of filter-sterilized 20% glycerol (vol:vol) to the second tube, resuspend the pellet and store at -80^{o}C as backup. Cells from this suspension can either be plated onto CVP medium or used for PCR at a later date.

2. **Isolation from Tubers**
   a. Tuber sample may be processed in groups 25-200 tubers/sample. Smaller batches, such as 25 tubers, allow for estimates of incidence, while larger tuber batches aid in determining pathogen presence.
   b. The stem ends of tubers can be sliced off and shipped for processing to save on shipping costs and decrease processing time. Be sure to include tuber periderm in samples on the stem ends.
   c. Wash tuber samples in tap water to remove soil prior to processing.
   d. Separate rotten from unrotten tubers during washing to avoid cross-contamination.
   e. Sterilize tools (submerge in 95% alcohol and flame excess alcohol) and work surface (wipe down with 70% alcohol) between samples.
   f. Change gloves between samples. Samples can also be cut on paper towels, which should be disposed of between samples.
   g. Using a clean and disinfected hand-held potato peeler[27] to remove one peel strip from each tuber that includes both the stem/heel end (stolon attachment) and rose ends[28].
   h. Rinse the tubers again and use a separate hand-held peeler or disposable scalpel to remove a small plug of tissue from the stolon end of each tuber in the sample (approximately 5-10 mm deep and wide) making sure not to take any peel.
   i. Place samples either into separate universal extraction bags, 12 mL sterile tubes or flasks.
   j. Add 15 mL 0.25 (quarter) strength Ringer's buffer containing Tetrasodium pyrophosphate (0.1% final concentration) or Dithiothreitol (0.75% final concentration) or Diethyldithiocarbamic acid (5% volume:volume) antioxidants[29] to each sample[23].
   k. Pulverise to give and oatmeal consistency.
   l. Shake samples 100 rpm for at least 2 h to allow for bacteria to stream out of samples.
   m. Remove 5 mL of solution and place in 15 mL sterile centrifuge tube.
   n. Add 5 mL of D-PEM[30] to select for growth of *Dickeya* and *Pectobacterium* species.
   o. Loosen lids of the 12 mL centrifuge tubes a quarter of a turn to allow for gas exchange and place in disposable anaerobic chambers with indicator.
   p. Place samples at 36-37^{o}C for 48 h under anaerobic (low oxygen) conditions to promote growth of *Dickeya* and *Pectobacterium* sp. Incubation temperatures above 33^{o}C kill or inhibit growth of many other plant-associated bacteria.
   q. Remove 100 μL and continue with **Step 5** if interested in obtaining *Dickeya* or *Pectobacterium* isolates.

[27] Clean and disinfect peeler between each sample by rising with 0.2 M Sodium hydroxide and then with 96% Ethanol and finally rising well with distilled (or tap) water. Allow to drain before peeling next sample
[28] Both tuber stem end sections containing the core and peel (92, 94) and tuber peels (93) have been used to detect soft rot bacteria on tuber samples and both have been shown to correlate with field incidence.
[29] Adding an antioxidant delays bacterial cell death by toxic substances present in extracts
[30] The amount of test material and PEM used may vary but the ratio to aim for is approx. 1:3 to 1:5 (w/v) tissue in S-PEM, and 1:1 (v/v) liquid sample in D-PEM.

3. **Isolation from Water**
    a. Collect 250 mL water samples in sterile containers. If possible collect the sample approximately 10-12 inches under the surface of water.
    b. Pack samples in shipping box with ice packets surrounding containers to keep samples cool.
    c. Ship to the laboratory and process within 24 h of collection.
    d. Subdivide into aliquots of 40 mL and clarify by centrifugation at a low speed (180 ×g) for 10 min.
    e. Remove 20 mL of supernatant and mix with an equal volume of D-PEM in 50 mL centrifuge tube. See Appendix B.14 on reconstituting D-PEM.
    f. Incubate in an anaerobically at 36-37 ^{o}C for 48 h.
    g. Centrifuge at 10,000 ×g to concentrate the bacterial fraction.
    h. Resuspend the pellet 1 mL sterile water.
    i. Make serial dilution and plate onto CVP medium to isolate single colonies.
    j. Alternatively, extract DNA from the resuspended pellet.

4. **Isolation from Soil**
    a. For soil/debris, remove stones, break up aggregates and cut plant tissues into small pieces.

5. **Plating**
    a. Spread 100 μL of each dilution for each sample onto duplicate CVP plates previously dried to remove excess surface moisture.
    b. You may also inoculate the 100 μL of homogenate in D-PEM and incubate under anaerobic conditions at 23-28^{o}C for 24 h prior to plating onto CVP.
    c. Incubate the CVP plates upside down with one plate at 27^{o}C and the other plate at 37^{o}C for 48 h to grow *Pectobacterium* and *Dickeya* species respectively.
    d. A dilution series of approximately 10^{-1} to 10^{-4} CFU mL^{-1} of a positive control for *Pectobacterium* and *Dickeya* spp. should also be prepared.
    e. Select well-spaced colonies or cavities per CVP plate and re-streak on to fresh CVP plate.
    f. Incubate plates at respective temperatures, 27^{o}C or 37^{o}C.
    g. Select colonies (cavities) from Step e., streak each on NA or LBA (See Appendix C.7 and C.3 respectively) plate previously dried to remove excess surface moisture.
    h. Incubate at 27^{o}C or 37^{o}C for about one weeks to ensure that only *Pectobacterium* and *Dickeya* colonies are present. SRP form round convex creamy-translucent colonies on either medium.
    i. You may also subculture bacterial colonies from Step g. onto NA medium slants until they are needed.

G

Extraction of Genomic DNA from Bacteria

The procedure has been adapted from a number of publications (such as Wilson (116)) and laboratories.

1. Inoculate 10-15 mL of NB or LB from a single colony of a pure fresh ($<$72 h) culture growing on NA or LBA.
2. Incubate while shaking at 27^{o}C for 18 h.
3. Harvest cells from this suspension by centrifugation for 10 min at 9,447 x *g*.
4. Resuspend the pellet in 500 μL of sterile distilled water and transfer to a clean 1.5 mL Eppendorf.
5. Alternatively, scrap bacterial growth off the surface of a freshly grown plate (NA or LBA) and suspended in 500 μL of sterile distilled water.
6. Add 20 μL lysozyme (Conc. 100 mg/mL) and mix well. This is step is necessary for hard to lyse gram (+) and some gram (-) bacteria.
7. Incubate for 30 min at 37^{o}C.
8. Add 40 μL of 10% SDS ($NaC_{12}H_{25}SO_4$) and mix well.
9. Add 8 μL Proteinase K (2 mg/mL). Mix well.
10. Incubate for 1-3 h at 56^{o}C. If cells are not lysed (as seen by cleared solution with increased viscosity), incubation can proceed overnight (16 h).
11. Add 100 μL of 5 M NaCl and mix well.
12. Add 100 μL of CTAB/NaCl (heated to 65^{o}C) and mix well.
13. Incubate at 65^{o}C for 10 min. [31]
14. Add 500 μL of Chloroform:Isoamyl alcohol (24:1), mix well and vortex.
15. Spin at 13,000 rpm for 10 min preferably at 4^{o}C to separate the phases.
16. Transfer the aqueous phase to a clean microfuge tube (should not be viscous)[32]
17. Repeat the Chloroform:Isoamyl alcohol extraction (Step 14) until no protein remains at the interphase otherwise proceed to Step 18.
18. Adjust the salt concentration by adding 1/10 volume of Sodium acetate, pH 5.2 and mix well. Total volume should approximately be 550 μL.
19. Add 2 volumes (1100 μL) of cold 100% Ethanol (calculated after salt addition).
20. Incubate overnight at -20^{o}C.
21. Spin at 13,000 rpm in a microfuge for 10 min at 4^{o}C.
22. Carefully decant supernatant. (change orientation of tube so that pellet is on opposite side).
23. Add 500 μL 70% ice-cold Ethanol to wash the pellet.
24. Spin at 13,000 rpm in a microfuge for 10 min at 4^{o}C.
25. Carefully decant supernatant.
26. Air dry the pellet for 60 min in a lamina fume hood or briefly vacuum to dry pellet.
27. Resuspend pellet in 100 μL TE buffer.
28. Measure purity and concentration on a Spectrophotometer.
29. Store at -20^{o}C for immediate use otherwise keep DNA at -80^{o}C for longer-term storage.

[31] Step 11 is very important since CTAB-nucleic acid precipitate will form if the salt concentration drops below 0.5 M at room temperature. The aim here is to remove cell wall debris, denatured protein, and polysaccharides complexed to CTAB (a cationic detergent), while retaining the nucleic acids in solution.

[32] This extraction removes CTAB-protein/polysaccharide complexes. A white interface should be visible after centrifugation. If interface isn't compact - remove with a sterile toothpick, re-centrifuge and collect the supernatant.

H

All samples positive for SRP

Table H.1: All samples confirmed to be infected with *Dickeya* and *Pectobacterium* species

No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRE		Subspecies			
									Pectobacterium spp.	*Dickeya* spp.	*Pa*	*Pb*	*Pc*	*Pp*
1	3	1862	MR-IMS-NKU-JK	Meru	Imenti South	Nkuene	Soil		+ve					
2	20	1389	MR-IMC-ABT-HM1	Meru	Imenti Central	Abothuguchi West	Soil		+ve					
3	22	2069	MR-IMC-ABT-MM	Meru	Imenti Central	Abothuguchi West	Stem	Shangi	+ve					
4	23	2138	MR-IMC-ABT-DK	Meru	Imenti Central	Abothuguchi West	Stem	Shangi	+ve		+ve			
5	24	2101	MR-IMC-ABT-SM1	Meru	Imenti Central	Abothuguchi West	Stem	Shangi	+ve					
6	30	1949	MR-IMC-ABT-KM	Meru	Imenti Central	Abothuguchi West	Stem	Shangi	+ve					
7	38	761	MR-IMC-ABT-FM2	Meru	Imenti Central	Abothuguchi West	Tuber	Asante	+ve					
8	40	1617	MR-IMS-ABG-FK3	Meru	Imenti South	Abogeta West	Stem	Shangi	+ve					
9	63	1839	MR-BRI-KSM-IM	Meru	Buuri	Kisima	Soil		+ve					
10	65	1698	MR-BRI-KSM-IM	Meru	Buuri	Kisima	Stem	Shangi	+ve					
11	82	1882	MR-BRI-KBR-JK3	Meru	Buuri	Kibirichia	Soil		+ve		+ve			
12	84	1919	MR-BRI-KSM-EK	Meru	Buuri	Kisima	Soil		+ve		+ve	+ve	+ve	
13	104	756	MR-BRI-KNA-ZM	Meru	Buuri	Kiirua/Naari	Tuber	Shangi	+ve					
14	114	1900	MR-BRI-KBR-AN	Meru	Buuri	Kibirichia	Soil		+ve				+ve	
15	167	1622	EL-KYN-KMR-HK	Elgeyo Marakwet	Keiyo North	Kamariny	Stem	Shangi	+ve					+ve
16	174	1653	EL-MRE-KPY-EC	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve					
17	180	1886	EL-MRE-KPY-GC2	Elgeyo Marakwet	Marakwet East	Kapyego	Soil		+ve					
18	181	1686	EL-MRE-KPY-TC	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve		+ve			+ve
19	186	1998	EN-MRE-KPY-JM	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve		+ve		+ve	+ve
20	187	144	EL-MRE-KPY-TM	Elgeyo Marakwet	Marakwet East	Kapyego	Stem	Shangi	+ve			+ve		
21	198	762	EL-MRW-KPS-AK	Elgeyo Marakwet	Marakwet West	Kapsowar	Tuber	Shangi		+ve				
22	204	1616	EL-MRW-KPS-MK	Elgeyo Marakwet	Marakwet West	Kapsowar	Stem	Shangi	+ve					
23	229	1639	EL-KYN-KPC-JK	Elgeyo Marakwet	Keiyo North	Kapchemutwa	Stem	Shangi	+ve					
24	274	1681	EL-KYS-KPT-JC2	Elgeyo Marakwet	Keiyo South	Kaptarakwa	Stem	Shangi	+ve					
25	292	1412	TN-CHR-MKT-SW	Trans Nzoia	Cherangany	Makutano	Soil		+ve					
26	343	1520	TN-SBT-KNY-JN	Trans Nzoia	Saboti	Kinyoro	Soil		+ve					
27	359	1691	TN-SBT-SBT-JC2	Trans Nzoia	Saboti	Saboti	Stem	Shangi	+ve					
28	360	1955	TN-SBT-SBT-EW	Trans Nzoia	Saboti	Saboti	Stem	Asante	+ve		+ve			
29	363	1980	TN-SBT-SBT-MK	Trans Nzoia	Saboti	Saboti	Stem	Shangi	+ve		+ve			+ve
30	365	1613	TN-SBT-SBT-JM	Trans Nzoia	Saboti	Saboti	Stem	Kabale	+ve				+ve	
31	393	902	NR-NRS-SGM-SC	Narok	Narok South	Sagamian	Soil		+ve					+ve
32	393	161	NR-NRS-SGM-SC	Narok	Narok South	Sagamian	Stem	Dutch Robijn	+ve			+ve		
33	394	784	NR-NRS-SGM-JR2	Narok	Narok South	Sagamian	Tuber	Dutch Robijn	+ve				+ve	+ve
34	396	924	NR-NRS-SGM-SS	Narok	Narok South	Sagamian	Soil		+ve					+ve
35	400	143	NR-NRS-SGM-WN	Narok	Narok South	Sagamian	Soil		+ve					
36	401	945	NR-NRS-SGM- AK	Narok	Narok South	Sagamian	Soil		+ve					
37	401	139	NR-NRS-SGM- AK	Narok	Narok South	Sagamian	Stem	Shangi	+ve					
38	412	177	NR-NRN-OLR-SK4	Narok	Narok North	Oloropil	Stem	Shangi	+ve			+ve		
39	412	860	NR-NRN-OLR-SK4	Narok	Narok North	Oloropil	Stem	Shangi	+ve					
40	412	59	NR-NRN-OLR-SK4	Narok	Narok North	Oloropil	Tuber	Shangi	+ve	+ve				
41	414	332	NR-NRN-OLR-JS	Narok	Narok North	Oloropil	Stem	Shangi	+ve			+ve		
42	419	910	NR-NRN-OLR-RY	Narok	Narok North	Oloropil	Soil		+ve			+ve		+ve
43	420	544	NR-NRN-OLR-SK2	Narok	Narok North	Oloropil	Soil		+ve			+ve		
44	420	345	NR-NRN-OLR-SK2	Narok	Narok North	Oloropil	Stem	Shangi	+ve					+ve
45	434	545	NR-NRN-MLL-ST	Narok	Narok North	Melili	Soil		+ve					
46	442	863	NR-NRN-MLL-SS	Narok	Narok North	Melili	Stem	Shangi	+ve					+ve
47	443	150	NR-NRN-MLL-SW	Narok	Narok North	Melili	Stem	Shangi	+ve					
48	444	550	NR-NRN-MLL-BI	Narok	Narok North	Melili	Soil		+ve					+ve
49	446	293	NR-NRN-MLL-SP	Narok	Narok North	Melili	Stem	Shangi	+ve					
50	447	512	NR-NRN-MLL-PJ	Narok	Narok North	Melili	Soil		+ve			+ve		

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRE		Subspecies			
									Pectobacterium spp.	*Dickeya* spp.	*Pa*	*Pb*	*Pc*	*Pp*
51	449	542	NR-NRN-MLL-NS	Narok	Narok North	Melili	Soil		+ve				+ve	+ve
52	450	178	NR-NRN-MLL-JT1	Narok	Narok North	Melili	Stem	Shangi	+ve		+ve	+ve	+ve	+ve
53	457	175	NR-NRE-KKN-DS2	Narok	Narok East	Keekonyokie	Stem	Shangi	+ve		+ve		+ve	
54	459	400	NR-NRE-KKN-AK	Narok	Narok East	Keekonyokie	Soil		+ve			+ve		
55	460	557	NR-NRE-IDM-NO	Narok	Narok East	Iidamat	Soil		+ve					
56	460	853	NR-NRE-IDM-NO	Narok	Narok East	Iidamat	Stem	Shangi	+ve					
57	463	854	NR-NRE-KKN-MN	Narok	Narok East	Keekonyokie	Stem	Shangi	+ve					
58	464	176	NR-NRE-KKN-PK	Narok	Narok East	Keekonyokie	Stem	Shangi	+ve					
59	471	52	NR-NRE-IDM-PN	Narok	Narok East	Iidamat	Tuber	Shangi	+ve					+ve
60	473	395	NR-NRE-KKN-JN	Narok	Narok East	Keekonyokie	Soil		+ve					+ve
61	476	137	NR-NRE-IDM-JM	Narok	Narok East	Iidamat	Stem	Shangi	+ve		+ve			
62	476	152	NR-NRE-IDM-JM	Narok	Narok East	Iidamat	Stem	Shangi	+ve					+ve
63	478	552	NR-NRE-KKN-MK	Narok	Narok East	Keekonyokie	Soil		+ve				+ve	
64	483	662	NR-NRE-KKN-AS	Narok	Narok East	Keekonyokie	Tuber	Shangi	+ve					
65	490	170	NR-NRS-SGO-HK	Narok	Narok South	Sogoo	Stem	Dutch Robijn	+ve			+ve	+ve	+ve
66	496	926	NR-NRS-SGO-MS	Narok	Narok South	Sogoo	Soil		+ve				+ve	
67	496	40	NR-NRS-SGO-MS	Narok	Narok South	Sogoo	Tuber	Dutch Robijn	+ve			+ve		
68	497	279	NR-NRS-SGO-AK	Narok	Narok South	Sogoo	Stem	Destiny	+ve					+ve
69	498	132	NR-NRS-SGO-WK1	Narok	Narok South	Sogoo	Soil		+ve		+ve			
70	498	398	NR-NRS-SGO-WK1	Narok	Narok South	Sogoo	Soil		+ve				+ve	+ve
71	499	929	NR-NRS-SGO-SK	Narok	Narok South	Sogoo	Soil		+ve					
72	501	304	NR-NRS-SGO-WS	Narok	Narok South	Sogoo	Stem	Dutch Robijn	+ve				+ve	
73	505	610	NR-NRE-IDM-DM	Narok	Narok East	Iidamat	Soil		+ve		+ve			
74	506	13	NR-NRE-IDM-FN	Narok	Narok East	Iidamat	Tuber	Shangi	+ve					
75	511	382	NR-NRE-IDM-MK	Narok	Narok East	Iidamat	Soil		+ve					
76	511	1558	NR-NRE-IDM-MK	Narok	Narok East	Iidamat	Soil		+ve				+ve	+ve
77	512	60	NR-NRE-IDM-PK	Narok	Narok East	Iidamat	Tuber	Shangi	+ve					+ve
78	515	53	NR-NRE-IDM-MP	Narok	Narok East	Iidamat	Tuber	Shangi	+ve					
79	516	453	NY-OLK-RRI-AK	Nyandarua	Ol Kalou	Rurii	Soil		+ve					
80	516	1197	NY-OLK-RRI-AK	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve					
81	517	322	NY-OLK-RRI-MM	Nyandarua	Ol Kalou	Rurii	Soil		+ve				+ve	
82	519	368	NY-OLK-RRI-GN	Nyandarua	Ol Kalou	Rurii	Soil		+ve					
83	520	163	NY-OLK-RRI-GM	Nyandarua	Ol Kalou	Rurii	Soil		+ve					
84	520	1277	NY-OLK-RRI-GM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve					
85	521	234	NY-OLK-RRI-SK	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve			+ve		+ve
86	526	585	NY-OLK-RRI-FI	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve					
87	529	82	NY-OLK-RRI-HM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve			+ve	+ve	+ve
88	529	1216	NY-OLK-RRI-HM	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve					
89	534	371	NY-OLK-RRI-PM2	Nyandarua	Ol Kalou	Rurii	Soil		+ve		+ve	+ve		
90	535	611	NY-OLK-RRI-NK	Nyandarua	Ol Kalou	Rurii	Soil		+ve					
91	535	883	NY-OLK-RRI-NK	Nyandarua	Ol Kalou	Rurii	Stem	Shangi	+ve					
92	538	394	NY-OLK-RRI-PM1	Nyandarua	Ol Kalou	Rurii	Soil		+ve					
93	541	262	NY-OLK-MRN-JM	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve				+ve	+ve
94	543	92	NY-OLK-MRN-MW	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve			+ve		
95	543	111	NY-OLK-MRN-MW	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve					
96	546	454	NY-OLK-MRN-CK	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve		+ve		+ve	
97	552	614	NY-OLK-MRN-JK	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve					+ve
98	555	612	NY-OLK-MRN-SW1	Nyandarua	Ol Kalou	Mirangine	Soil		+ve			+ve		
99	560	372	NY-OLK-ML-BN	Nyandarua	Ol Kalou	Mirangine	Soil		+ve					
100	560	930	NY-OLK-ML-BN	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve					+ve
101	562	197	NY-OLK-MRN-MN	Nyandarua	Ol Kalou	Mirangine	Soil		+ve					
102	562	228	NY-OLK-MRN-MN	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve				+ve	

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRE		Subspecies			
									Pectobacterium spp.	*Dickeya* spp.	*Pa*	*Pb*	*Pc*	*Pp*
103	564	1275	NY-OLK-MRN-PN3	Nyandarua	Ol Kalou	Mirangine	Stem	Shangi	+ve					
104	571	219	NY-OLK-KNJ-CM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve					
105	573	344	NY-OLK-KNJ-SN	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve				+ve	
106	574	251	NY-OLK-KNJ-LM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve			+ve		
107	575	1201	NY-OLK-KNJ-JM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve					
108	577	623	NY-OLK-KNJ-MW	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve					+ve
109	580	1168	NY-OLK-KNJ-EW	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve					
110	584	1220	NY-OLK-KNJ-PM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve					
111	587	340	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve					
112	587	341	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve					
113	587	456	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Soil		+ve		+ve			+ve
114	587	567	NY-OLK-KNJ-AM	Nyandarua	Ol Kalou	Kanjuiri Ridge	Stem	Shangi	+ve					
115	591	1010	NY-NDR-SHM-DW	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
116	591	1147	NY-NDR-SHM-DW	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
117	592	96	NY-NDR-SHM-BM	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
118	592	113	NY-NDR-SHM-BM	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve		+ve	+ve		
119	594	237	NY-NDR-SHM-PK2	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					+ve
120	596	1043	NY-NDR-SHM-PM1	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
121	598	874	NY-NDR-SHM-MM1	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
122	605	91	NY-NDR-CNT-JN2	Nyandarua	Ndaragwa	Central	Stem	Shangi	+ve					+ve
123	605	598	NY-NDR-CNT-JN2	Nyandarua	Ndaragwa	Central	Stem	Shangi	+ve					
124	606	487	NY-NDR-SHM-LN	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
125	610	973	NY-NDR-SHM-JN1	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
126	611	256	NY-NDR-SHM-PM2	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve		+ve	+ve		
127	613	880	NY-NDR-SHM-KI	Nyandarua	Ndaragwa	Shamata	Stem	Shangi	+ve					
128	616	578	NY-OLJ-GTH-MN1	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
129	617	129	NY-OLJ-GTH-JM3	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve				+ve	
130	617	878	NY-OLJ-GTH-JM3	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
131	617	904	NY-OLJ-GTH-JM3	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
132	618	381	NY-OLJ-GTH-MM2	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
133	620	122	NY-OLJ-GTH-LI	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve			+ve		
134	621	86	NY-OLJ-GTH-MM1	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
135	621	221	NY-OLJ-GTH-MM1	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
136	622	541	NY-OLJ-GTH-JR	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
137	622	121	NY-OLJ-GTH-JR	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					+ve
138	622	265	NY-OLJ-GTH-JR	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
139	624	546	NY-OLJ-GTH-MK	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
140	624	95	NY-OLJ-GTH-MK	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
141	625	361	NY-OLJ-GTH-SK1	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
142	625	971	NY-OLJ-GTH-SK1	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
143	627	506	NY-OLJ-GTH-AM2	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
144	627	80	NY-OLJ-GTH-AM2	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					+ve
145	628	270	NY-OLJ-GTH-JM2	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
146	629	524	NY-OLJ-GTH-LM	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
147	629	609	NY-OLJ-GTH-LM	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve		+ve			
148	629	1031	NY-OLJ-GTH-LM	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve					
149	631	245	NY-OLJ-GTH-DG	Nyandarua	Ol Joro Orok	Gathanje	Stem	Shangi	+ve				+ve	
150	632	504	NY-OLJ-GTH-AW	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
151	633	482	NY-OLJ-GTH-AM1	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
152	640	97	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve		+ve	+ve	+ve	
153	640	500	NY-NDR-KRT-PM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve					+ve
154	642	179	NY-NDR-KRT-CK	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve				+ve	

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRE		Subspecies			
									Pectobacterium spp.	*Dickeya* spp.	*Pa*	*Pb*	*Pc*	*Pp*
155	643	308	NY-NDR-KRT-RW	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve					
156	643	900	NY-NDR-KRT-RW	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve					
157	646	568	NY-NDR-KRT-SM	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve					
158	648	79	NY-NDR-KRT-MK1	Nyandarua	Ndaragwa	Kiriita	Tuber	Shangi	+ve			+ve		+ve
159	653	213	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve			+ve	+ve	+ve
160	653	225	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve			+ve		+ve
161	653	601	NY-NDR-KRT-NN	Nyandarua	Ndaragwa	Kiriita	Stem	Shangi	+ve					
162	657	114	NY-KPR-WNJ-HN	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve					
163	658	2062	NY-KPR-KPR-SK2	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve					
164	659	314	NY-KPR-KPR-IM	Nyandarua	Kipipiri	Kipipiri	Soil		+ve					
165	659	240	NY-KPR-KPR-IM	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve			+ve		
166	661	389	NY-KPR-KPR-HM	Nyandarua	Kipipiri	Kipipiri	Soil		+ve			+ve		
167	663	236	NY-KPR-KPR-JK1	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve			+ve	+ve	
168	664	307	NY-KPR-KPR-JN2	Nyandarua	Kipipiri	Kipipiri	Soil		+ve					
169	664	1203	NY-KPR-KPR-JN2	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve					
170	665	855	NY-KPR-KPR-LM	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve		+ve			
171	672	507	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Soil		+ve			+ve		
172	672	249	NY-KPR-KPR-JGK	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve		+ve	+ve	+ve	+ve
173	673	2723	NY-KPR-KPR-JN1	Nyandarua	Kipipiri	Kipipiri	Tuber	Shangi	+ve					
174	676	1060	NY-KPR-KPR-AM1	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve					
175	676	1070	NY-KPR-KPR-AM1	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve					
176	677	1072	NY-KPR-KPR-PM2	Nyandarua	Kipipiri	Kipipiri	Stem	Shangi	+ve					
177	687	450	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Soil		+ve		+ve		+ve	+ve
178	687	619	NY-KPR-WNJ-MM	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve		+ve	+ve	+ve	
179	694	254	NY-KPR-WNJ-JM1	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve		+ve			
180	694	577	NY-KPR-WNJ-JM1	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve					
181	695	1219	NY-KPR-WNJ-DC	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve		+ve		+ve	
182	696	206	NY-KPR-WNJ-PG	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve					
183	696	1248	NY-KPR-WNJ-PG	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve					+ve
184	698	875	NY-KPR-WNJ-PN	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve					+ve
185	698	921	NY-KPR-WNJ-PN	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve				+ve	
186	702	621	NY-KPR-WNJ-SM	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve					
187	705	539	NY-KPR-WNJ-LM1	Nyandarua	Kipipiri	Wanjohi	Stem	Shangi	+ve			+ve	+ve	
188	709	241	NY-KPR-NYK-SK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					+ve
189	709	273	NY-KPR-NYK-SK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					
190	714	1000	NY-KPR-NYK-JC	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					
191	714	1039	NY-KPR-NYK-JC	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					+ve
192	714	1195	NY-KPR-NYK-JC	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					
193	719	1100	NY-KPR-NYK-PK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve		+ve			
194	719	1256	NY-KPR-NYK-PK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve				+ve	
195	721	927	NY-KPR-NYK-CN	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve		+ve	+ve		
196	722	1150	NY-KPR-NYK-FM	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					
197	727	1198	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Soil		+ve			+ve		
198	727	260	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve		+ve			
199	727	530	NY-KPR-NYK-JK	Nyandarua	Kipipiri	Nyakio	Stem	Shangi	+ve					+ve
200	730	976	NY-KNG-NYK-DK	Nyandarua	Kinangop	Nyakio	Stem	Shangi	+ve					
201	730	1176	NY-KNG-NYK-DK	Nyandarua	Kinangop	Nyakio	Stem	Shangi	+ve					
202	735	1190	NY-NDR-CNT-MK2	Nyandarua	Ndaragwa	Central	Stem	Shangi	+ve					
203	740	2469	NY-NDR-CNT-DM2	Nyandarua	Ndaragwa	Central	Tuber	Shangi	+ve					
204	745	1069	NY-NDR-CNT-JN1	Nyandarua	Ndaragwa	Central	Stem	Shangi	+ve					
205	750	160	NY-NDR-CNT-JM	Nyandarua	Ndaragwa	Central	Stem	Shangi	+ve					
206	753	1272	NY-NDR-CNT-KK	Nyandarua	Ndaragwa	Central	Stem	Shangi	+ve					

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRE		Subspecies			
									Pectobacterium spp.	*Dickeya* spp.	*Pa*	*Pb*	*Pc*	*Pp*
207	760	131	NY-KNG-MGM-PK1	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve					
208	761	168	NY-KNG-MGM-LG	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve		+ve		+ve	+ve
209	761	1019	NY-KNG-MGM-LG	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve					
210	764	348	NY-KPR-MGM-GM	Nyandarua	Kipipiri	Magumu	Soil		+ve					
211	764	229	NY-KPR-MGM-GM	Nyandarua	Kipipiri	Magumu	Stem	Dutch Robijn	+ve					
212	764	1233	NY-KPR-MGM-GM	Nyandarua	Kipipiri	Magumu	Stem	Dutch Robijn	+ve					
213	765	140	NY-KPR-MGM-SN	Nyandarua	Kipipiri	Magumu	Soil		+ve			+ve		
214	771	1083	NY-KPR-MGM-JW	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve					
215	773	1084	NY-KPR-GTA-JN2	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve					
216	774	1024	NY-KPR-GTA-GK	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve					
217	775	590	NY-KPR-GTA-PM	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve					
218	776	1101	NY-KPR-MGM-JM3	Nyandarua	Kipipiri	Magumu	Soil		+ve					
219	777	405	NY-KPR-MGM-PN	Nyandarua	Kipipiri	Magumu	Soil		+ve					
220	780	231	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Stem	Dutch Robijn	+ve			+ve	+ve	
221	782	561	NY-KNG-MGM-MG	Nyandarua	Kinangop	Magumu	Soil		+ve					
222	784	387	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Soil		+ve					+ve
223	784	411	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Soil		+ve					
224	784	1112	NY-KNG-MGM-GN	Nyandarua	Kinangop	Magumu	Stem	Dutch Robijn	+ve					
225	785	1266	NY-KPR-MGM-JM3	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve					
226	786	338	NY-KNG-MGM-RM	Nyandarua	Kinangop	Magumu	Soil		+ve					
227	790	412	NY-KPR-MGM-MK	Nyandarua	Kipipiri	Magumu	Soil		+ve					
228	790	259	NY-KPR-MGM-MK	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve		+ve	+ve	+ve	
229	795	220	NY-KNG-MGM-RM	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve					
230	795	1141	NY-KNG-MGM-RM	Nyandarua	Kinangop	Magumu	Stem	Shangi	+ve					
231	796	99	NY-KPR-MGM-LN	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve					+ve
232	796	1169	NY-KPR-MGM-LN	Nyandarua	Kipipiri	Magumu	Stem	Shangi	+ve					
233	806	347	NY-OLJ-WRU-MM	Nyandarua	Ol Joro Orok	Weru	Soil		+ve					
234	809	942	NY-OLJ-WRU-MN	Nyandarua	Ol Joro Orok	Weru	Stem	Shangi	+ve					
235	818	195	NY-OLJ-CHR-JK	Nyandarua	Ol Joro Orok	Charagita	Soil		+ve		+ve	+ve		
236	822	373	NY-OLJ-CHR-MM	Nyandarua	Ol Joro Orok	Charagita	Soil		+ve					+ve
237	825	426	NY-KPR-GTA-DM1	Nyandarua	Kipipiri	Geta	Soil		+ve					
238	826	428	NY-KNG-MRG-HN1	Nyandarua	Kipipiri	Murungaru	Soil		+ve					
239	827	1118	NY-KNG-MRG-PN	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve					
240	829	1252	NY-KNG-MRG-JM	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve					
241	831	239	NY-KNG-MRG-PM	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve		+ve			
242	833	582	NY-OLJ-CHA-JG	Nyandarua	Ol Joro Orok	Charagita	Stem	Shangi	+ve					
243	836	380	NY-OLJ-WRU-LN	Nyandarua	Ol Joro Orok	Weru	Soil		+ve					+ve
244	838	2495	NY-KPR-GTA-DM1	Nyandarua	Kipipiri	Geta	Tuber	Shangi	+ve					
245	838	2602	NY-KPR-GTA-DM1	Nyandarua	Kipipiri	Geta	Tuber	Shangi	+ve					
246	840	384	NY-KPR-GTA-SG	Nyandarua	Kipipiri	Geta	Soil		+ve					
247	841	429	NY-KPR-GTA-GM	Nyandarua	Kipipiri	Geta	Soil		+ve		+ve	+ve		
248	841	1154	NY-KPR-GTA-GM	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve					
249	842	572	NY-KPR-GTA-DM1	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve					
250	846	996	NY-KPR-GTA-JN2	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve					
251	847	316	NY-KPR-GTA-MN	Nyandarua	Kipipiri	Geta	Soil		+ve					
252	848	190	NY-KPR-GTA-GK	Nyandarua	Kipipiri	Geta	Soil		+ve					
253	848	1056	NY-KPR-GTA-GK	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve					
254	849	960	NY-KPR-GTA-SM2	Nyandarua	Kipipiri	Geta	Stem	Shangi	+ve			+ve		
255	857	211	NY-OLJ-WRU-EW	Nyandarua	Ol Joro Orok	Weru	Stem	Shangi	+ve			+ve	+ve	
256	859	535	NY-OLJ-GTH-MN3	Nyandarua	Ol Joro Orok	Gathanje	Soil		+ve					
257	865	1078	NY-KNG-MRG-HN2	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve					
258	871	1089	NY-KNG-MRG-JN3	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve			+ve		

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No.	Farm No.	Sample No.	Code	County	Sub-county	Ward	Sample type	Variety	SRE		Subspecies			
									Pectobacterium spp.	*Dickeya* spp.	*Pa*	*Pb*	*Pc*	*Pp*
259	871	1157	NY-KNG-MRG-JN3	Nyandarua	Kipipiri	Murungaru	Stem	Dutch Robijn	+ve					
260	873	556	NY-KNG-NKG-PC	Nyandarua	Kipipiri	North Kinangop	Soil		+ve					
261	874	438	NY-KNG-NKG-GK	Nyandarua	Kipipiri	North Kinangop	Soil		+ve					
262	876	562	NY-KNG-NKG-SG	Nyandarua	Kipipiri	North Kinangop	Soil		+ve					
263	877	440	NY-KNG-NKG-TW	Nyandarua	Kinangop	North Kinangop	Stem	Dutch Robijn	+ve					+ve
264	878	342	NY-KNG-NKG-PK	Nyandarua	Kipipiri	North Kinangop	Soil		+ve			+ve		
265	880	536	NY-KNG-NKG-RK	Nyandarua	Kinangop	North Kinangop	Soil		+ve			+ve		
266	882	523	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Soil		+ve			+ve		
267	882	235	NY-KNG-NKG-JN	Nyandarua	Kipipiri	North Kinangop	Stem	Dutch Robijn	+ve		+ve	+ve	+ve	
268	885	427	NY-KNG-NKG-TN	Nyandarua	Kinangop	North Kinangop	Soil		+ve					
269	898	2238	NK-NJR-MNR-BG	Nakuru	Njoro	Mau Narok	Stem	Shangi	+ve					
270	902	2250	NK-NJR-MNR-EK	Nakuru	Njoro	Mau Narok	Stem	Shangi	+ve					
271	916	1750	NK-GLG-ELM-AN	Nakuru	Gilgil	Elementaita	Soil		+ve					
272	931	2328	NK-GLG-ELM-SM	Nakuru	Gilgil	Elementaita	Stem	Shangi	+ve					
273	939	2222	NK-NVS-BSH-PN2	Nakuru	Naivasha	Biashara	Stem	Shangi	+ve				+ve	
274	950	2383	NK-NJR-NSS-MK	Nakuru	Njoro	Nessuit	Stem	Shangi	+ve					
275	953	2270	NK-NJR-MCH-JS1	Nakuru	Njoro	Mauche	Stem	Dutch Robijn	+ve		+ve			
276	959	2152	NK-NJR-NSS-AC1	Nakuru	Njoro	Nessuit	Stem	Shangi	+ve		+ve			
277	976	2168	NK-MLO-ELB-SM	Nakuru	Molo	Elburgon	Stem	Shangi	+ve					
278	997	2331	NK-MLO-ELB-JM3	Nakuru	Molo	Elburgon	Stem	Shangi	+ve					
279	1004	2171	NK-KRS-AML-CN	Nakuru	Kuresoi South	Amalo	Stem	Shangi	+ve					
280	1026	1894	NK-KRS-AML-FC	Nakuru	Kuresoi South	Amalo	Soil		+ve					
281	1052	1350	NK-BHT-NDN-CM	Nakuru	Bahati	Ndundori	Soil		+ve					
282	1091	1308	NK-MLO-MLO-JM1	Nakuru	Molo	Molo	Soil		+ve					
283	1091	2200	NK-MLO-MLO-JM1	Nakuru	Molo	Molo	Stem	Shangi	+ve					+ve
284	1112	2181	NK-MLO-MLO-JG	Nakuru	Molo	Molo	Stem	Shangi	+ve					
285	1117	1892	NK-MLO-MLO-JN2	Nakuru	Molo	Molo	Soil		+ve					
286	1150	2198	NK-KRS-KRN-RL	Nakuru	Kuresoi South	Keringet	Stem	Shangi	+ve					
287	1155	2392	NK-KRS-KRN-MK	Nakuru	Kuresoi South	Keringet	Stem	Shangi	+ve					
288	1186	1434	NK-KRS-KRN-BC	Nakuru	Kuresoi South	Keringet	Soil		+ve		+ve			
289	1194	2340	NK-KRS-AML-RR	Nakuru	Kuresoi South	Amalo	Stem	Shangi	+ve					+ve
290	1195	45	NK-KRS-AML-CB	Nakuru	Kuresoi South	Amalo	Stem	Shangi	+ve					
291	1224	2227	NK-KRS-AML-RK	Nakuru	Kuresoi South	Amalo	Stem	Shangi	+ve					

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Addendum

Surveillance to establish extent of *Dickeya* species

Dickeya spp. was identified on two farms, Elgeyo Marakwet (Farm 198) and Narok (Farm 412) (Table 6.1). The two farms were identified and a team from KEPHIS conducted a contact tracing exercise from the 3^{rd} to 7^{th} November 2020. Contact tracing was supported by the rationale that most farmers depend on the informal seed system and either save own planting materials or share planting materials amongst themselves. The two farmers were interviewed to gain an understanding of how they obtain planting materials and with whom they share the materials. Farmer of Farm 198 is the main supplier of potato planting materials in Marakwet West and supports every grower in the region with planting materials, agro-inputs, agronomic advice and market information. Although the farmers in the sub-county understand the importance of planting certified seed potato, there is no registered certified seed supplier and farmer of Farm 198 is the main seed merchant. Tuber samples were collected from three farmers who had obtained potato planting materials from Farm 198 and additional tuber samples from Farm 198. Farmer of Farm 412 sourced initial potato planting materials from the main market in Narok town. The farmer sells and also exchanges potato planting materials with neighbours and friends but also obtains materials from other farmers. Subsequently, tuber samples were obtained from eight farmers from whom Farmer of Farm 412 exchanged or obtained tubers and additional tuber samples obtained from Farm 412. Isolation of *Dickeya* species were conducted as previously explained (Section 4.4.2). Molecular confirmation was conducted as detailed in Section 4.6. *Dickeya* species was confirmed in samples collected from 5 of the 12 farms representing a proportion of 42%. One of the samples was identified as *D. solani* using the SOL-A primer set published by Pritchard et al. (117).

Table I.1: Result from additional surveillance conducted in Elgeyo Marakwet and Narok counties

Farmer	County	Sub-county	Ward	Latitude	Longitude	Result
412	Narok	Norok North	Oloropil	-0.75971	35.8894	+ve
1244	Narok	Norok North	Oloropil	-0.75875	35.8877	-ve
1245	Narok	Norok North	Oloropil	-0.71347	35.8989	-ve
1246	Narok	Norok North	Oloropil	-0.72314	38.8986	-ve
1247	Narok	Norok North	Oloropil	-0.72314	38.8986	+ve
1248	Narok	Norok North	Eneneleetia	-0.69237	35.9061	-ve
1249	Narok	Norok North	Eneneleetia	-0.71047	35.9012	-ve
1250	Narok	Norok North	Eneneleetia	-0.71404	35.9050	-ve
1251	Narok	Norok North	Eneneleetia	-0.69855	35.9030	+ve
198	Elgeyo Marakwet	Marakwet West	Kapsowar	-0.92202	35.5631	+ve
1252	Elgeyo Marakwet	Marakwet West	Kapsowar	-0.92273	35.5636	+ve
1253	Elgeyo Marakwet	Marakwet West	Kapsowar	-0.92230	35.5603	-ve
1254	Elgeyo Marakwet	Marakwet West	Kapsowar	-0.92911	35.5619	-ve

This additional surveillance exercise was funded by CABI's Action on Invasives Programme.

Addendum

Surveillance by KALRO in Taita Taveta County

A surveillance was conducted by a team from KALRO in Taita Taveta county. Using Loop-Mediated Isothermal Amplification (LAMP) assays, they detected *Dickeya* sp. specifically *D. solani* and *D. dianthicola*. This work was presented at the 3rd Phytosanitary Conference that took place from 13th to 16th September 2021 in Nairobi, Kenya. The conference was organised by KEPHIS and the Centre of Phytosanitary Excellence (COPE) and supported financially by CABI.

On-Field Detection of the Genus *Pectobacterium* and *Dickeya* Causing Black Leg in Taita Taveta County, Kenya

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Potato (*Solanum tuberosum*) is the second most important crop after maize in Kenya and plays a major role in addressing the government's development agenda on food and nutrition security. However its production is constrained by several factors including diseases of phytosanitary and economic importance. Blackleg disease, is a major disease of potato caused by plant pathogenic bacteria in the genera *Pectobacterium* and *Dickeya*. These bacteria cause stem wilts and rots and tuber soft rots causing production losses and rejection of stocks during certification process globally. Rapid, cost effective, accurate and efficient detection of plant pathogens is crucial for disease management. Loop-mediated isothermal amplification (LAMP) is a robust nucleic acid amplification method that works under isothermal conditions making it suitable for field testing. Blackleg causing bacteria was recently reported in Taita Taveta County and the study aimed at evaluating the operability of field detection for genus *Pectobacterium* and *Dickeya* using LAMP. The assay detected both *Pectobacterium* and *Dickeya* using generic primers from crude extracts of potato stem and tuber tissues within 30 minutes. The earliest time to positivity for the genus *Dickeya* was 4.30 and 6.30 minutes for stem and tuber *respectively* while for genus

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