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Digital Revolution in Farmer Fields: VarScout Unveils Kenya's Varietal Landscape – The Case of Potato

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CONTENT

ABSTRACT

This paper reports on data collected through VarScout, a digital crowdsourcing tool, to monitor varietal adoption, turnover, seed use, and yields. Key findings for the case of potato in Kenya include: (1) Shangi is the dominant variety, covering 73% of the area, followed by Steven (7%) and Sherekea (6%); (2) the weighted average varietal age is 9.3 years, with newer varieties performing better; (3) 19.5% of farmers use clean seed, with higher adoption in Nakuru (21.5%) compared to Bungoma (1.5%); (4) farmers using clean seed achieve 1.5 t/ha higher yields than those using saved seed. The study demonstrates the utility of VarScout for cost-effective data collection, while highlighting the need for further methodological improvements and ground-truthing. The findings underscore the significant impact of CIP's breeding efforts, with over 50% of the pedigree of key popular varieties linked to CIP's genebank. The paper provides insights to inform seed system interventions and guide future breeding priorities in Kenya.

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I. INTRODUCTION

Varietal Varietal data for key food crops in developing countries are often scattered, inaccurate and infrequently updated. However, data, metrics, and indicators are key for decision-making on breeding investments and seed systems development/interventions. Without simple yet essential data on, for instance, “what” varieties were cultivated “where” and “for how long”, an understanding of the degree to which smallholder farmers are benefiting from introduced genetic gain in terms of higher yields, better nutrition, better preparedness against negative consequences of climate change, poverty, etc. is not possible.

Any meaningful analysis of such outcomes prerequires an understanding of adoption rates of varieties, their trends and performance, their seed sources and classes, turnover, and replacement rates. Semi-structured surveys are frequently relied on to collect such data which often include comprehensive sets of questions to better understand impact (of improved varieties or other technologies) on farmer-level outcomes. Unfortunately, such surveys and linked research implementations are frequently highly costly and consequently carried out only intermittently.

To collect adoption and varietal performance data, more cost-effective alternatives based on crowdsourcing1 or citizen science have more recently received attention in the agricultural research for development sector (Ryan et al., 2018; van Etten et al., 2019; Ebitu et al., 2021). ClimMob for instance, is an innovative and free online platform designed to facilitate participatory seed testing projects through agricultural citizen science. It allows smallholder farmers to conduct small-scale trials on their own land, gathering valuable data that can inform agricultural practices and technology suitability (Quirós et al., 2024)VarScout which is a recently developed digital ecosystem to collect, store, and visualize varietal data, is another example of using crowdsourcing for cost-effective collection of varietal data. Anyone can collect data in real time using phones or tablets for key indicators, such as varietal name, area planted, production, and seed source and replacement rates. It is important to note that VarScout (and other more recent approaches) do not intend to replace in-depth surveys and related impact assessment studies; they, however, provide cost-effective alternatives for key data points around adoption of technologies (and varietal performance) in farmer fields, which can inform decision-making and research designs.

The objective of this paper is to report on data collected through VarScout using the potato crop in Kenya as a study example. A secondary objective is to “ground-truth” the data collected through VarScout with existing evidence, where available. Data was collected between June-November 2024 through the extension program in Bungoma, Meru, and Nakuru counties.

The paper is organized as follows. In section 2, background information is provided for potato in Kenya with a focus on production trends and common sector challenges. Section 3 describes methods and data used. In section 4, the results are reported which are discussed in section 5. Finally, section 6 concludes and offers ways forward.

[1] “Crowdsourcing is the practice of obtaining needed services, ideas, or content by soliciting contributions from a large group of people, particularly through online platforms. This approach allows organizations and individuals to leverage the collective intelligence and resources of the crowd, often leading to innovative solutions and diverse inputs that would be difficult to achieve through traditional means. Crowdsourcing can involve various activities, including idea generation, data collection, and problem-solving, often incentivized through monetary rewards or recognition for participants” (adapted from Perplexity.ai, 2024).

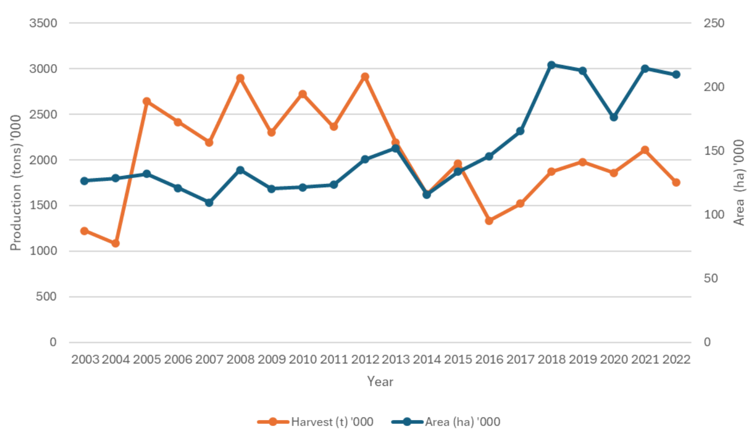
II. BACKGROUND

Production, area, yield in Kenya

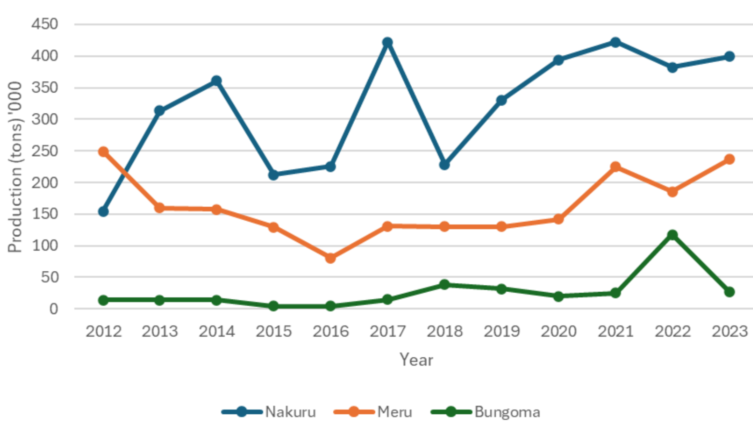
In Kenya potato is grown on rain-fed area twice a year during the long rains (March to May) and short rains (October-December) (Janssens et al., 2013). In 2024, the total area cultivated to potato is about 240k ha. Since 2015, the area planted has increased by 33% from initial 150k, a sharp increase which has not been matched by increased production. In fact, annual production has stagnated at the 2M metric tons mark since 2015 (Figure 1a). At county level, Nakuru is the most-important potato growing area of Kenya where production increased by 167% within 12 years from 150k metric tons in 2012 to 400k metric tons in 2023. Meru and Bungoma are also increasingly important in potato production which in 2023 stands at 240k metric tons and180k metric tons, respectively (Figure 1b).

Yields hovered at the 20t/ha mark between 2002-2012, then declined radically to 13t/ha between 2013-15, and have since reached a low point below the 10t/ha mark (Figure 1c). Various reasons can be at play, for instance weather variability leading to longer drought spells (Karanja et al., 2014) , poor crop management, including under-utilization of inputs (Kwambai et al., 2023), which is also related to the more recent price spikes for fertilizers and other inputs (BCG, 2022), but also widespread use of farmer-saved seed (Nkurumwa et al., 2018).

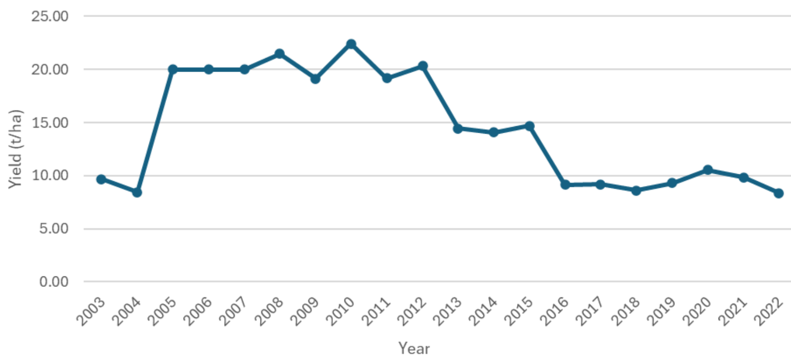
Figure 1. Trends in Potato Production, Area, and Yields for Kenya and selected Counties between 2003-2023.



(a) Trend in Potato Production and Area in Kenya between 2003-2022.



(b) Production and Area for selected Counties in Kenya between 2012- 2023.



(c) Yield in Kenya between 2003-2022.

Source: FAOSTAT, 2024; KilimoSTAT, 2024.

Kenya's seed system

The formal seed system in Kenya supplies about 5% of the total seed requirements (Kaguongo et al., 2007). Seed demand in 2023 would be about 400k tons, considering a potato area of 240k ha and assuming a planting rate of 2t/ha. With a mere of about 30 registered seed merchants in Kenya who produce and distribute certified seed, demand for certified seed by far exceeds its availability (E. O. Atieno et al., 2023) which contributes to the mentioned low average national potato yields. In addition to certified seed, quality declared seed (QDS) can be a strategy to increase the availability of quality seed while lowering the costs of clean seed. Quality is usually assured through reputation of the seed producer or entity (Hirpa et al., 2016; Louwaars & De Boef, 2012; Schulz et al., 2013). Seed production can then also take place in a decentralized manner, further increasing access, availability, and cost-effectiveness of production of potato clean (QDS) seed. At this stage, however, QDS is not recognized as a formal seed class, deeming the production and trade illegal (Kaguongo et al., 2014; Muthoni et al., 2014). The informal seed system is dominating the supply of seed. Farmers re-use their own saved seeds – usually small tubers from the previous season but also acquire seeds of unknown quality from local markets and neighbours (Gildemacher et al., 2011;Kaguongo et al., 2014). Quality of farmer-saved seed is unknown and cannot be inspected at the time of exchange or market transactions. Degeneration of seed quality which is caused by seed-borne pests and diseases built-up over time (Gildemacher et al., 2011; Gildemacher et al., 2009;Janssens et al., 2013; Kaguongo et al., 2014; Thomas-Sharma et al., 2016 ; Were et al., 2013), results in a yield penalty which increases in the duration of re-using farmer-saved seed. Given that certified seed is more expensive than re-using saved seed, farmers are often disincentivized to purchase certified clean seed every season, even though attainable yields are higher.

There are various institutional reforms that have been made in the past, including training potato farmer organizations and farm enterprises to multiply, store and market seed potatoes, and giving licences to private seed inspectors (McEwan et al., 2021). Private companies, including Agri-Seed Co., Stokman Rozen Kenya, and Agrico East Africa, Kisima Farm, Suera Farm, and Genetics Technology International Limited have emerged to produce and provide farmers with certified seed potatoes (E. Atieno & Schulte-Geldermann, 2016). These companies' partner with various research institutions and the government to produce high yielding potato varieties which are resistant to diseases. Private sector players in the potato value chain, including Amiran Kenya and John Deere, provide small and medium scale farmers with machinery and equipment, such as planters, harvesters, and sprayers for potatoes. Other companies provide inputs, such as fertilizers and pesticides. Availability of clean seed through the private sector remains a major bottleneck, with demand far exceeding supply.

III. METHODS AND DATA

VarScout explained

The primary data collection tool used is called *VarScout*[2] which is a recently developed, released, and publicly available digital ecosystem to collect, store, and visualize crop varietal data. It is a crowdsourcing tool that farmers, extension officers, enumerators, traders – anyone – can use with mobile devices, such as tablets or smart phones. Collected data is uploaded into a cloud, processed, and visualized using heat maps in real time. As a digital crowdsourcing method, it is cost-effective relative to other more labour and resource-heavy data collection methods. *VarScout* is currently being used for monitoring seed systems development and biodiversity conservation. Resonanz GmbH, a Swiss-based software developer, has been a critical partner for the co-development of *VarScout*.

Data collection through extension program

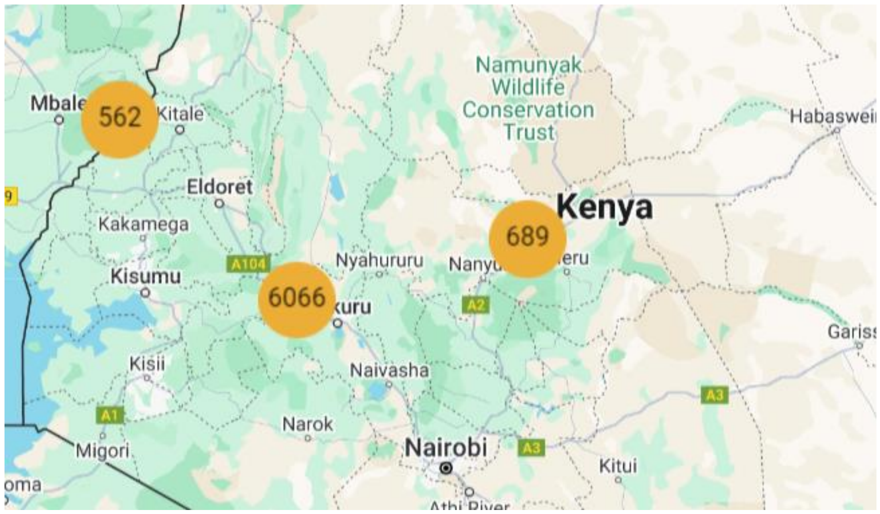
For the data collection of this paper, about 60 extension officers in Kenya were trained in June 2024 in the use of *VarScout*. Extension officers all received travel allowance and internet/airtime vouchers to be able to visit farmers. They also received a hard copy of the potato release cataloque for Kenyato improve on visual inspection. Extension officers were instructed to visit every household "on their regular route". This allowed for a systematic data collection. For each household visited, extension officers collected data on four staple food crops, such as potato, sweetpotato, maize, and beans. In addition, all extension officers were incentivised to collect and upload data by participating in a lottery and to win a tablet which was awarded to four so-called "VarScout Digital Champions" with the most uploaded data points. Prior to this engagement, awareness was created among local government in Nakuru county and approvals granted by county leadership for the implementation of *VarScout*.

Data

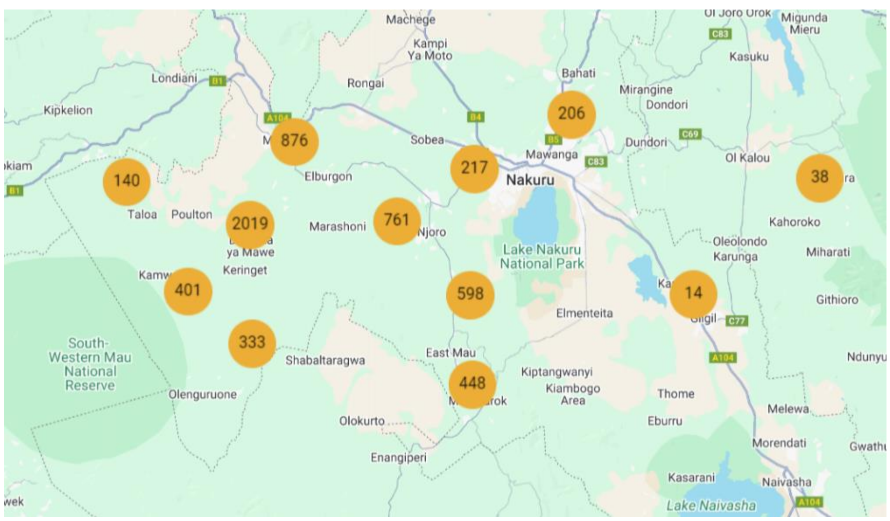
Data collection took place in Nakuru, Bungoma, and Meru counties between June-November, 2024. Important to note is the cut-off date of November 18. Beyond that date, more data have become available which are not considered in this paper. Data were collected for four crops (i.e., maize, potato, sweetpotato, beans) which were in farmers' fields at the same time. For potato - the focus of this paper - a total of some 7,317 observations were collected. As depicted in Map 1a, most of the data was collected in Nakuru county (6,066 observations), followed by Meru county (689 observations) and Bungoma county (562 observations). Map 1b further details the spread of data points in Nakuru county with observations representing the county's major potato producing areas. The data was collected by the county's respective extension officers.

[2] *VarScout* can be downloaded in the app stores of related Android- and Apple-based devices. A browser version can be accessed at https://www.varscout.org/ (accessed Oct 2024).

Map 1. Number of unique data points for "potato adoption" between June 1 – November 18, 2024.



(a) Kenya



(b) Nakuru

Source: VarScout (www.varscout.org)

VarScout allows for the collection of key agricultural metrics and indicators along with demographic identifiers, such as grower name, age, and gender. Agricultural metrics include variety name, area planted to variety, production, and adopted seed class and seed replacement rates. If year of varietal release was uploaded in VarScout beforehand (for officially released varieties), the weighted average varietal age, a measure of varietal turnover, was calculated using the formular offered by (Brennan & Byerlee, 1991).

Data accuracy is also of key importance for VarScout. Currently, GPS coordinates can be used in VarScout to accurately calculate the area cultivated. Additional research is ongoing to use artificial intelligence-based image recognition for varietal identification, for which a proof of concept was recently established for wheat. Similar cutting-edge approaches are envisioned for yield predictions.

IV. RESULTS

This section is divided into four parts that include results on varietal adoption, varietal turnover, seed classes and replacement, and yield performance. Beforehand, some basic demographic and socio-economic descriptive statistics are presented.

Descriptive statistics

About 60% of the respondents were male. The average respondent was 45 years of age at the time of data collection, had total agricultural land of 1.64 ha and cultivated potato on 0.53 ha. Disaggregated by County, there are no significant differences except for potato area. In Nakuru county, average area planted to potatoes was 1.73 ha compared with 1.3 ha (about 25% less) in Bungoma and Meru.

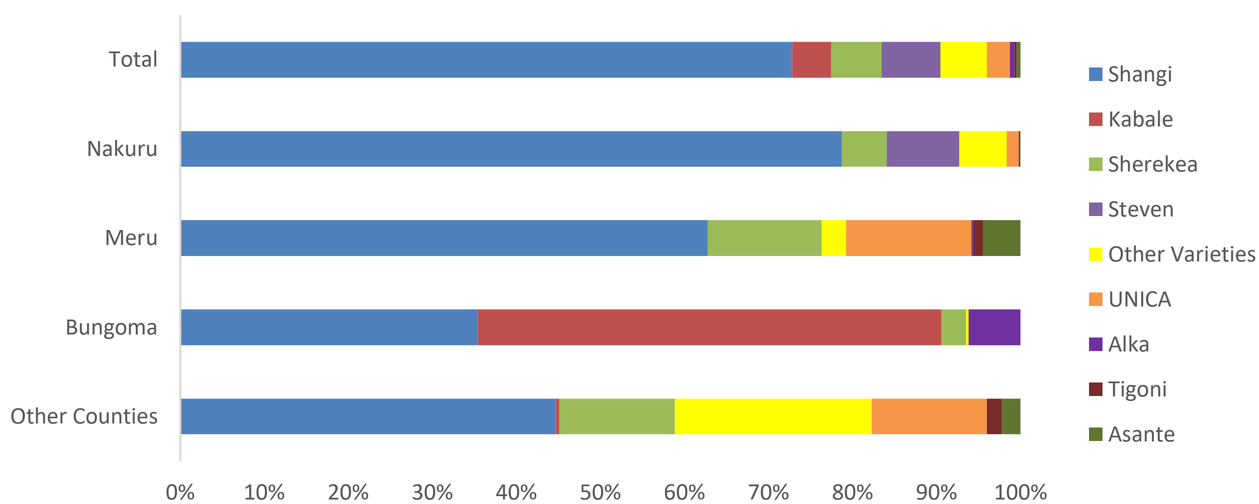
Table 1. Averages for descriptive statistics.

Variable	Nakuru	Bungoma	Meru	Total sample
Male respondent	60.1	63.6	64.2	60.8
Age (years)	45.32	45.51	45.31	45.32
Total area (ha)	1.73	1.32	1.30	1.64
Potato area (ha)	0.56	0.33	0.52	0.53

Varietal adoption in 2024

Figure 2 presents the varietal adoption rates of potato in Kenya and selected counties. Overall, Shangi is the most dominant variety in terms of adoption (73%), followed by Steven (7%) and Sherekea (6%). In Nakuru county, Shangi had the highest adoption rate (79%), followed by Steven (9%) and Sherekea (5%). In Meru, adoption rate was highest for Shangi (63%), followed by Unica (15%) and Sherekea (14%). In Bungoma county, Kabale had the highest adoption rate (55%), followed by Shangi (35%) and Alka (6%), respectively. For other counties where potato is grown, Shangi variety had the highest adoption (45%) followed by other varieties (23%) and Unica (14%). See Table 1A in the Appendix for more variety-specific details on production rates and area.

Figure 2. Adoption of varieties in Kenya and by selected counties in 2024.



Varietal turnover is an important metric to assess the extent to which farmers are turning over their varieties and thus benefit from new genetics. This is different from seed replacement which is turning over clean seed of the same variety with same genetic base. Here we report varietal age as we only have a single year of observations. In total, 6,444 out of 7,317 observations were utilized meaning that 873 observations (or 12% of total sample) are missing which are varieties without known, available, or recorded year of release information and are thus likely local landraces, escapes, or from neighbouring countries. Steven is one of these landraces and at present the exact DNA is unknown. Kabale is a Ugandan variety found in Bungoma county which borders with Uganda.

Varietal age was 10.7 years on average in 2024. This is mainly driven by the relatively low varietal age observed in Nakuru (9.33 years). In Bungoma, the varietal age averaged 22.7 years (Table 2). Weighting the varietal age by area to planted varieties do not considerably change the findings. This suggests that newer varieties which initially cover smaller areas were not increasingly adopted which is reasonable given the "youngest" varieties in our sample date back to mid-2010s (10 years ago), which is the same as the observed average.

Table 2. Varietal Age & Weighted Average Varietal Age (WAVA) in Kenya by County in 2024.

County	Observations	Varietal Age		WAVA	
		Mean	(Std dev)	Mean	(Std dev)
Nakuru	5,130	9.33	(1.44)	9.31	(1.3)
Bungoma	576	22.73	(11.16)	24.0	(10.9)
Meru	565	10.54	(4.27)	8.2	(1.1)
Other Counties	173	10.73	(4.46)	10.9	(5.1)
Total	**6,444**	**10.7**	**(5.4)**	**9.3**	**(1.6)**

Seed classes and replacement rates

Several seed classes are used by Kenyan farmers. Certified seed is often considered the "best quality" seed class as it gives farmers the highest genetic return – however, also comes with an often-high investment costs. On the other extreme is farmer-saved seed, while not being a seed class, is a practice in which parts of the potato production is kept or saved as seed for the next season. *VarScout* collects data on "certified seed", but measurement error cannot be ruled out. For instance, respondents could refer to other than certified seed, such as clean or quality seed which is arguably still of high quality. Cognizant of this, in what follows the term "clean seed" is used which includes certified, clean, and quality seed, and means that seed was purchased in the year of planting (i.e., 2024).

In 2024, 19.5% of respondents used clean seed while 80.5% have saved their seed from the previous season (Table 3). Regional differences exist with 21.5% of farmers in Nakuru use clean seed, 1.5% in Bungoma, and 20.6% in Meru. The results further suggests that 19.5% of farmers purchased seed in the same year of planting and thus "participate" in the formal seed sector. The small share of farmers purchasing clean seed in Bungoma (1.5%) is reasonable, given the county is relative more remotely located and access to clean is limited as no seed companies are operating in Bungoma.

Table 3. Adoption of Clean Seed Potato in Kenya by County in 2024.

County	Observations	Clean seed	
		(#)	(%)
Nakuru	5,987	1,287	21.5
Bungoma	616	9	1.5
Meru	583	120	20.6
Other counties	226	7	3.1
Total	**7,412**	**1,423**	**19.2**

Use of clean seed[3] also differs by variety. For instance, 34.1% of farmers who plant Sherekea use clean seed of Sherekea variety. Clean seed for Steven is used by 25.9% of Steven-planting farmers. The same holds for 19.6% of Unica-planting farmers and 16.9% of Shangi-planting farmers (Table 4). This suggests that some varieties are traded more in the formal seed system, while other varieties' seed is often saved by farmers from season to season or year to year. Also, within the category "other varieties" the share of farmers using clean seed is high (>40%). Unsurprisingly, for Shangi, a high percentage (83.1%) of respondents save seed. While the reason could be economic and farmers are unwilling to pay substantially for clean seed every season, (un)availability of clean seed is equally a challenge.

Table 4. Adoption of Clean Seed Potato in Kenya by Variety in 2024.

County	Observations	Clean seed		Farmer-saved seed
		(#)	(%)	(%)
Sherekea	446	152	34.1	65.9
Steven	518	134	25.9	74.1
Unica	204	40	19.6	80.4
Shangi	5,400	912	16.9	83.1
Kabale	341	0	0.0	100
Other varieties	503	185	36.8	63.2
Total	**7,412**	**1,423**	**19.2**	**80.8**

The finding that 80.8% save seed suggest that the use of farmer-saved seed is an important strategy for farmers. In words of seed replacements, this means that 19.2% of respondents replaced their seed after 0 years (Table 5). Some 21.7% of respondents did not use clean seed in 2024 but used seed from the previous year (seed replacement in 2023). Similarly, 11.5% of respondents used seed from 2022 for potato production in 2024. The figures are indicative, and we note that 40.8% of respondents did not specify a year. However, most respondents used seed which is not older than 2 years. Possibly, after year 2, using deteriorated farmer-saved seed becomes unviable due to the associated high yield penalty.

[3] Clean seed refers to certified seed, quality-declared seed, but also seed that was purchased from neighbours, traders, etc., and thus quality is unknown.

Table 5. Seed replacement rates by County.

County	Obs.	After 0 years (2024)	After 1 year (2023)	After 2 years (2022)	After 3 years (2021)	After 4 years (2020)	After 5 years (2019)	Older	Year not specified
	(#)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Nakuru	5,987	21.5	21.8	12.9	4.3	1.5	0.5	0.3	37.5
Bungoma	616	1.5	20.5	1.3	0.8	0.8	1.5	7.6	66.1
Meru	583	20.6	30.2	11.2	0.9	0.3	0.3	0.0	36.5
Other counties	226	3.1	3.1	3.1	5.8	4.0	4.0	5.8	71.2
Total	**7,412**	**19.2**	**21.7**	**11.5**	**3.7**	**1.4**	**0.7**	**1.0**	**40.8**

Notes: * seed replacement after 1 year means that seed was last purchased in 2023 as the reference year was 2024.

Yield performance

Yields are found to average 13.7t/ha. By county, yields in Meru are the highest (17.9t/ha) and the lowest in Bungoma (5.8t/ha), while in Nakuru yields average 13.8t/ha (Table 6). Yield performance differs by variety (Table 7). Steven is the highest-yielding variety (16.3t/ha), followed by Unica (15.6t/ha), and Sherekea (15t/ha). Shangi, being the most preferred variety, yields 1.5t/ha less than Shereka. Kabale is the lowest-yielding variety (5.3t/ha).

Disregarding Steven, which is not officially releases, and considering Shangi exhibiting relatively older genetics (see note in Table 7), the findings suggest that yield performance is negatively correlated with varietal age. In different words, "younger" varieties have a higher yield potential compared with their "older" counterparts. Unica – released in 2016 – yields an average of 15.6, Shereka – released in 2010 – yields an average of 15t/ha, and Shangi – released in 2015 but exhibiting much older genetics – yields 13.6t/ha.

Table 6. Yields in Kenya in 2024 by County.

County	Observations	Yield*
		(t/ha)
Nakuru	5,884	13.8
Bungoma	272	5.8
Meru	490	17.9
Other counties	81	12.3
Total	**6,727**	**13.7**

Notes: *the yields are significantly different at the 1%-significance level.

Table 7. Yields in Kenya in 2024 by Variety.

Variety	Year of release	Obs.	Yield*
			(t/ha)
Steven	-	509	16.3
Unica	2016	164	15.6
Sherekea	2010	379	15.0
Shangi	2015[T]	5,076	13.6
Kabale	1992	192	5.3
Other varieties	-	407	14.6
Total		**6,727**	**13.7**

Notes: *the yields are significantly different at the 1%-significance level; [T] Shangi was formally released in 2015 but farmers grew Shangi already in mid 2000s.

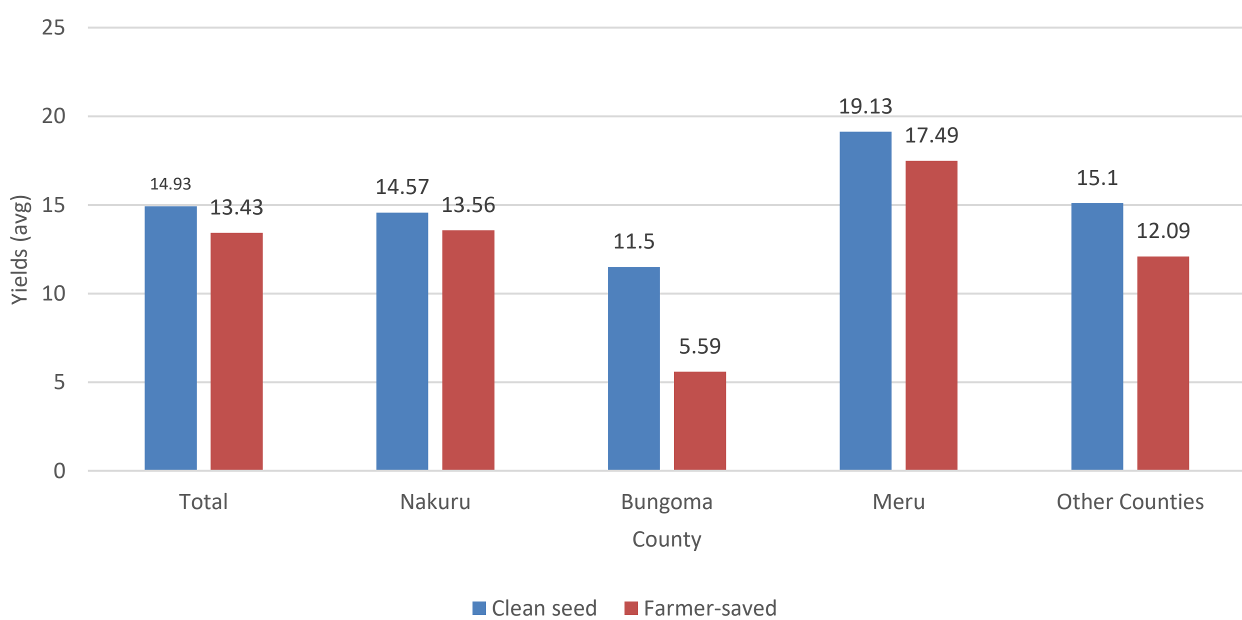
Table 8. Yields in Kenya in 2024 by County & Variety.

County	Varieties	Obs.	Yield (t/ha)
Nakuru	Shangi	4,636	13.4
	Steven	509	16.3
	Sherekea	314	14.4
Bungoma	Shangi	69	7.2
	Kabale	192	5.3
	Other	11	4.7
Meru	Shangi	308	18.4
	Unica	76	17.2
	Sherekea	63	17.9
Other Counties	Shangi	63	13.0
	Unica	5	12.4
	Other	11	8.5

In addition, varietal performance differs across locations, which can be due to agro-ecological conditions but also different management practices because of access to extension services, remoteness, etc. For instance, Shangi performs best in Meru (18.4t/ha) and worst in Bungoma (7.2.t/ha), a reduction of close to 50%. In Nakuru, Shangi yields still 13.4t/ha. Similar findings are observed for Steven and Unica (Table 8).

Farmers with clean seed achieve 1.5t/ha higher yields than those farmers who are not using clean seed (14.9t/ha - 13.4t/ha)(Fig 3). Comparing counties, in Nakuru, farmers who use clean seed achieve 1t/ha more than farmers who save their seed (14.5t/ha - 13.5t/ha). In Meru, the "clean seed effect" is 1.6t/ha while in Bungoma the effects of clean seed are the most striking (11.5t/ha – 5.6t/ha = 5.9t/ha).

Figure 3. Yield differences by use of Clean Seed in Kenya in 2024.

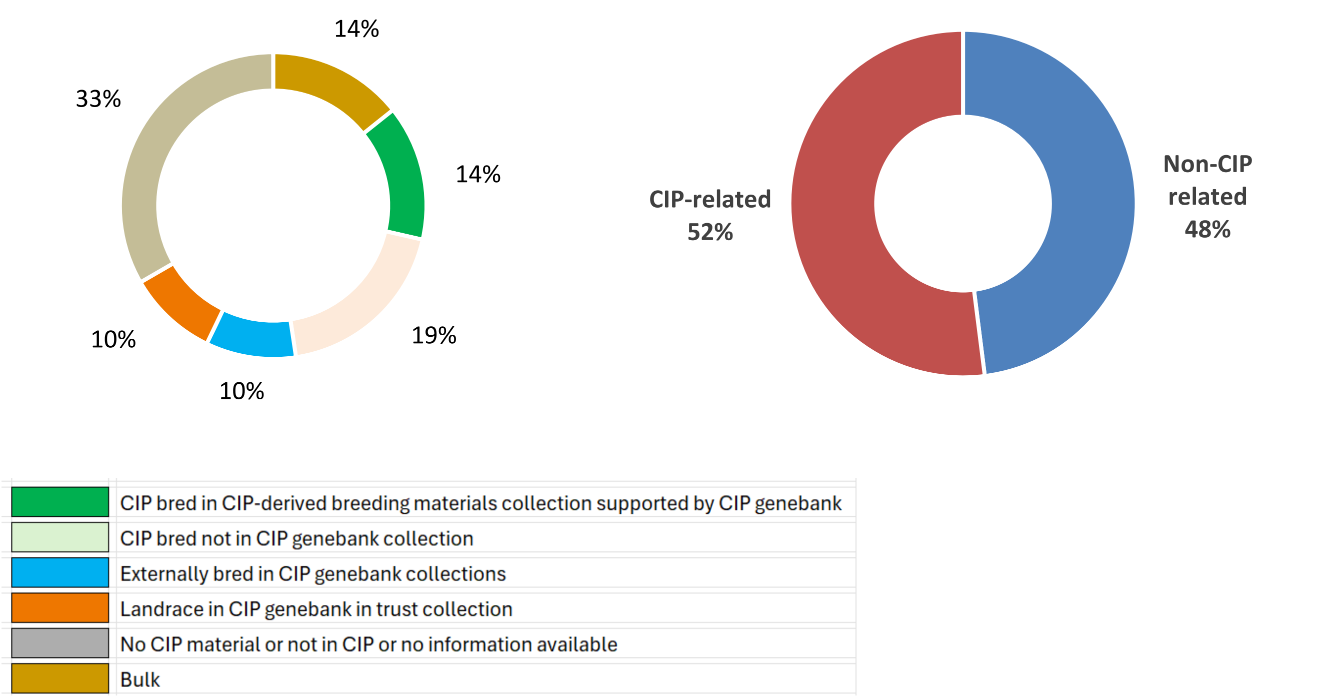


One way of assessing the impact of the Genebank is by looking into the genealogy of varieties and trace back the pedigree to CIP Genebank. In Kenya, for Shangi and Steven, the most dominant varieties in our sample, the exact relationship to CIP Genebank is unknown. For Sherekea, however, we know that 52% of its pedigree is related to the CIP Genebank while 48% of its pedigree is not (see Figure 4). Please also refer to Figure A1 in the Appendix which shows results for Wanjiku which – co-incidentally – also has a 52% relationship with material safeguarded in the CIP Genebank.

V. DISCUSSION

In Kenya, there have been several rounds of releases of new varieties during the past decades making better genetics available to farmers. In total, 77 varieties have been released between 1952 and 2024. Shangi was among these and released in 2015 after it had already been widely grown in farmers' fields. Shangi, however, can be considered an escape. This means that it escaped from the breeding program, ended-up in farmers' fields, and disseminated spontaneously across the country due to its preferred traits, such as early maturity, multi-purpose, low dormancy, and cooking quality (NPCK, 2022). Only after its formal release, quality seed production commenced.

Figure 4. Contribution of CIP Genebank to Sherekea Pedigree**.**



We found that Shangi is adopted by 73% of farmers and is thus the most important variety grown in Nakuru county, one of Kenya's most important potato growing regions. The National Potato Council of Kenya (NPCK) reports in 2022 that Shangi has a market share of 80% (NPCK, 2022). Similarly high adoption rates were found in a study conducted in 2019 using 225 households in North-Western parts of Kenya (Kwambai et al., 2023; Kwambai et al., 2024). Another more dated study reports adoption rates of Shangi to be higher than 70% (Kaguongo et al., 2014). Further ground-truthing of the data with more rigorous methods to collect varietal identity, such as DNA fingerprinting or artificial intelligence-based image recognition, will be important in future exercises.

In Bungoma, Kabale has been observed as the most important variety. This is striking as Kabale is an escape from Uganda where it is a preferred variety. The shared border between Bungoma and Uganda provides ample opportunity for informal trade and exchange of Kabale into Kenya. In Kenya, Kabale has not been officially released despite it is considered a “NARS-CIP” variety.

Overall, CIP breeding efforts in Kenya has been highly successful. All varieties monitored through VarScout have a direct relationship with CIP breeding material. Shangi is dominating the potato sector and there is evidence that some of the CIP-NARS varieties released between 2010 and 2017 (especially Sherekea, Unica and Wanjiku) are being adopted by farmers. Unfortunately, at this stage trend information on how adoption rates change over time is unavailable. Therefore, it is also not known if Shangi is being replaced by more recently released varieties. Striking is equally that no other releases, in particular through the private sector (which were released post 2013) are not being picked up by our data and are likely clustered in “other varieties”. More (and higher frequency) data is needed for other counties to better understand if adoption rates of private sector varieties are equally marginal, which may have important implications for the private businesses, and noting that many of them are targeted at specific processing market segments which are still developing.

On informal sector, we found that 14% of respondents still cultivate landraces, escapes, or varieties from neighbouring countries. The relatively small share of landraces confirms a larger trend towards adoption of improved varieties (see for instance (Gatto et al., 2021). “Steven” which is widely cultivated by Kenyan farmers in Nakuru may be a landrace or an escape. While the exact genetic identity of Steven is currently unknown, a relationship with CIP breeding material is likely and evidence from an undergoing DNA fingerprinting analysis will shed more light on its origins.

Varietal age was 10.7 years on average and WAVA 9.3 years. While in Nakuru and Meru adopted varieties were even younger (9.33 and 10.54 years, respectively), Bungoma varieties were the oldest (29 years). There are several reasons for this. Varietal turnover may be higher in Nakuru and Meru because these are “less remote” areas where agricultural sector and seed systems are more developed allowing more better access and availability of inputs and output markets. The dominant variety Shangi – officially released in 2015 – likely drives the results. If Shangi was released at a time it escaped some 20 years prior its formal release date in 2015, which would also more adequately represent its genetic vintage, the WAVA indicator would look more similar that of Bungoma (some 30 years). Therefore, caution needs to be applied when interpreting WAVA data using seemingly young varieties but with much older genetics. That said, WAVA analysis is still useful once a baseline or reference point is established. More data points across time are needed to fully exploit WAVA.

Regarding the use of clean seed, some 21.5% of respondents use clean seed in Nakuru compared with a mere 1.5% in Bungoma. This finding is corroborated by a recent study conducted in another North-Western County in Kenya where 4.9% of respondents used certified seed. Seed availability was mentioned as a key limiting factor (Kwambai et al., 2023). The higher rate found in Nakuru is also reasonable given the importance of the county for potato production and the availability of certified seed produced locally by private sector (Kephis, 2024). In contrast, considering a 400k tons of national clean seed demand and a production of <10k tons annually, the found 19.2% adoption of clean seed, appears to be (too) high. We do recognize that the adoption of clean seed does not represent the strict category of certified seed only. Rather, other seed classes, such as quality declared seed or whatever respondents consider “clean seed” is included as well. Another interesting finding is that some 25% of Steven-cultivating farmers reported to use clean seed, a variety with (currently) unknown genetics. This suggests that farmers may have misidentified Steven. Measurement error in “clean seed” may also contribute to this finding. Furthermore, Kabale farmers are not using clean seed which is reasonable given Kabale is a local variety from Uganda and not released in Kenya and hence clean seed is unavailable and farmers rely on more farmer-saved seed.

Quality seed availability has been found as a clear constraint to clean seed adoption and different seed production methods, such as apical rooted cuttings are promising to increase seed availability while reducing production costs (IFC, 2019). High costs associated with the purchase of clean seed is another constraint to adoption of clean seed. From an economic perspective, farmers often have little incentive to purchase clean certified or quality seed on an annual basis. The additional income generated from using clean seed every year cannot offset the initial high annual costs of clean seed, even when considering a yield penalty of some 5% annually from using recycled seed due to disease built-up.

Strategies to reduce these constraints would be to increase availability of clean material, for instance by further promoting cost-effective seed production methods such as apical rooted cuttings. Another strategy could be to make many potato farmers also seed multipliers. One bag of certified seed of high quality could then be multiplied in the first short rain season between March-July. During the long rain season between October and January, the multiplied seed (6-10x) will then be planted for ware or processing purposes. On the demand side, more emphasis needs to be placed on understanding the economic circumstances of farmers and how to support farmers to bear the initial high seed costs, through credit schemes, for instance.

On seed replacement rates, the results suggest that "saving seed" is an important seed strategy for farmers. With more than 50% of respondents save their seed for up to 2 years, before replacing these. From an economic perspective, this is reasonable as the high costs of seed disincentivizes farmers to replace their seed on an annual basis. Disease accumulation remains an important issue considerably affecting yields (Thomas-Sharma et al., 2016) and the spread of seed borne diseases, such as bacterial wilt and potato cyst nematode by increased diffusion of seed of unknown quality (McEwan et al., 2021; Tessema & Tesfaye, 2023).

Regarding yields, the reported 13.7t/ha (mainly representing Nakuru potato farming) is well above observed national yields in Kenya of about 8-9t/ha (FAOSTAT, 2024). This difference is mainly due to the strong focus on Nakuru, an important potato growing area which under-emphasizes other areas where yields are lower. Indeed, in Nakuru and Meru yields are the highest (13.8 and 17.9t/ha), while farmers in Bungoma receive poor yields of 5.8t/ha. Official statistics from these counties show average yields of 7.99t/ha (in Nakuru), 12.64t/ha (in Bungoma) and 9.61t/ha (in Meru), respectively (KilimoSTAT, 2023). This is in stark contrast to our findings, where yields in Bungoma are smaller (not higher) than in Nakuru. Further assessments will be needed to verify this.

Another striking finding is that farmers who use clean seed achieve 1.5t/ha more yields than those farmers who are not using clean seed. This underscores the importance of using clean seed for achieving higher yields. We also expected that using newer genetics (i.e., more recent varietal releases) would be positively correlated with higher yields in farmers' fields. Such a finding would provide evidence of the importance of breeding (programs). For the two most cultivated varieties we can argue that such a positive relationship between new genetics and yields exists. Shangi exhibiting old genetics from 1990s – yields 13.6t/ha, while Shereka, exhibiting much more recent genetics and released in 2010, yields 15t/ha. With more data coming in and number observations increase for more varieties, the effects may be disentangled, and clearer attribution of yield increases can be made to either "seed" or "genetics".

In terms of impacts of CIP genebank, we found that 52% of both Sherekea and Wanjiku varieties can be attributed to the CIP genebank. We propose that also 52% of (any kind of) impacts observed can be attributed to the CIP genebank. Observed adoption rates, production, and yield gains brought about by improving varieties, can thus all be attributed to the CIP genebank by about 50%. To understand the full impact of CIP genebank, ideally all adopted varieties are scrutinized based on their pedigree relationship to the CIP genebank. Unfortunately, for Shangi and Steven, the most dominating varieties, the pedigree is unknown.

Using *VarScout* for collecting key agricultural indicators was successful in the context of potato in Nakuru county. Success here refers to the uptake of *VarScout* as a digital ecosystem by the extension program of the national government of Nakuru. *VarScout* added value to the “daily work” of extension officers. Representativeness of data was achieved in Nakuru county by “visiting every farmer” on route of an extension officer and recording if farmers cultivated either maize, potato, or beans. There was zero overlap in the farmer visits. *VarScout* further collected data on key respondent variables, such as gender, age, area under potato cultivation. Our findings can be corroborated with findings from other studies (Agbolosoo et al., 2021; Muthoni et al., 2013; Njuguna et al., 2015). Disaggregating the varietal, seed, and performance data by these demographic and socio-economic data will be an important avenue of future analyses. While imperfect, area could be used as a proxy for wealth. Meaningful insights could be generated on “what type of farmer” is adopting, replacing new varieties and seed.

Success further refers to the relative cost-effectiveness of data collection compared with other data collection methods. For Kenya, the variable costs include provision of *VarScout* training to extension officers and feedback sessions, technical backstopping during data collection, but also costs to cover logistics. Add to this fixed costs for research and development, staff time for data analysis, or for maintenance and further improvements of *VarScout* software, which can be substantial. Increasing number of use cases for VarScout and getting buy-in from other CGIAR Centers will be important to cover parts of the fixed costs.

CONCLUSION

The objective of this paper is to update our insights on key agricultural indicators for potato farming in Kenya using *VarScout* as the means of data collection. The government extension officers in Nakuru and Meru Counties utilized *VarScout* and collected some +7,000 data points for potato within 6 months (June-November) in 2024. Agricultural data include area, yields, and seed replacement rates, which are all collected at the varietal level. Pre-uploaded varietal release data (by country) into *VarScout* allows for automated calculations and visualization of weighted average varietal age (WAVA). Other pre-uploaded varietal information in *VarScout* is on agronomic performances and morphological characteristics which increase accuracy of identification of varieties done by inspection.

In spite of these visual aid, data is still based on farmer recollection for varietal identity and yields. Further methodological research is needed to increase accuracy of data using cost-effective methods which allow for quick turnaround. Deep learning algorithms for yield predictions in wheat are already available and a first model for varietal identification is being tested. This is an area of high potential with more investments needed for creating algorithms for varietal identification and yields predictions for potato and sweetpotato crops. Area measurements are taken by using GPS coordinates which is already build into *VarScout*.

In terms of the actual findings, we found that CIP has a major footprint in the potato sector of Nakuru, Meru, and Bungoma, with more than 80% of adopted varieties are related to CIP material. The most important variety is Shangi – an escape from the breeding program found in farmers' fields already in the 1990s and officially released retrospectively only in 2015. The CIP-NARS variety Shereka, released in 2016, is another noteworthy example. By tracing back the pedigree of Shereka, we found that 50% of its material is originating from the CIP Genebank, underscoring the importance of the genebank for breeding and the Kenyan potato sector. Where pedigree data is available for varieties, this exercise could shed more light on the impacts of CIP Genebank.

Extension officers experienced *VarScout* as an added value to their daily work, supporting them to collect and store relevant information. Further institutionalizing data collection through *VarScout* is envisioned which includes the scaling-up to other Kenyan counties and including more crops. Currently, maize and beans data collected besides potatoes. The production of periodically, standardized, and automated reports from the data will be an important next step to inform decision making. Establishing a strong business case for *VarScout* will be needed to ensure the (financial) sustainability of *VarScout*.

The second objective was to "ground-truth" the data collected through *VarScout* with existing evidence, where available. Here we find mixed evidence. For example, adoption rates for Shangi, the most dominant variety in Kenya covering some 80% of the area, are similar to those reported in the literature. In turn, average yields in Nakuru are much higher compared with those reported in national official statistics. Here, more data is needed, ideally using methods that measure yields more accurately, to verify the results, such as image recognition based on AI or spectrometers.

Overall, the use of *VarScout* allows for low-cost data collection of key agricultural data in real time making it an attractive tool for monitoring varietal data over time and rapidly assess seed sectors and its development. While at present data is based on farmer recollection, the intention of *VarScout* data is to offer insights that spark more interest and raise more questions. These can then be followed up on, depending on the research objectives, with increased rigor (e.g., DNA fingerprinting), and research designs (e.g., randomized controlled trials) for outcome assessments.

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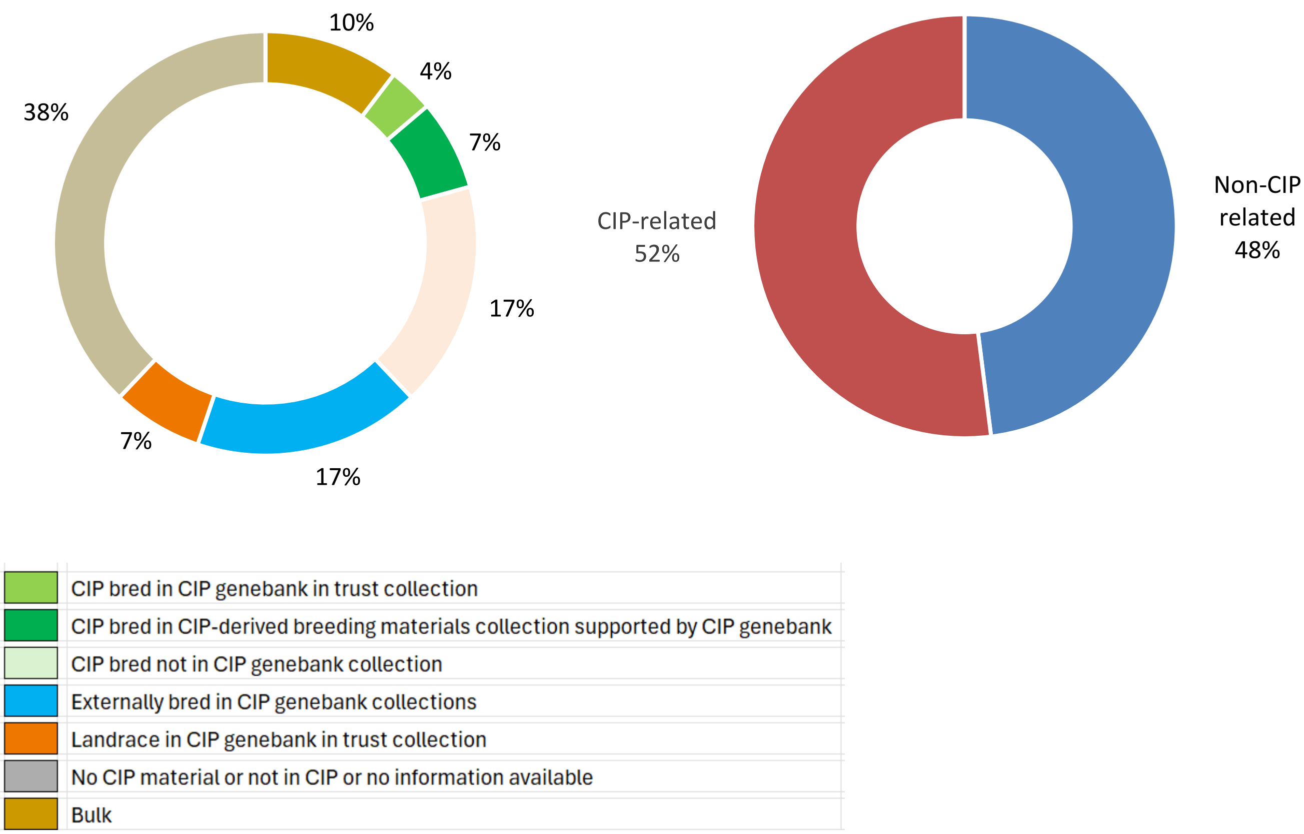
APPENDIX

Table 1A. Potato adoption, production, and area by variety in Kenya in 2024

Rank	Variety	Year of Release	Adoption rates		Production		Area	
			(#)	(%)	(tons)	(%)	(ha)	(%)
1	Shangi	2015	5,400	72.85	20,592.1	70.7	47181.3	83.5
2	Steven	-	518	6.99	2,954.0	10.1	1,512.6	2.6
3	Sherekea	2010	446	6.02	2,916.9	10.0	3,538.9	6.2
4	Kabale	1991*	341	4.60	309.4	1.1	84.6	0.2
5	Unica	2016	204	2.75	679.6	2.3	3454.9	6.1
	Other Varieties		503	6.79	1,660.0	4.8	726.7	1.4
6	Dera Ciana	-	93	1.25	197.2	0.6	578.9	1.1
7	Markies	2014	71	0.96	235.7	0.8	17.68	0.0
8	Wanjiku	2017	69	0.93	142.4	0.5	30.8	0.1
9	Alka	-	40	0.54	18.6	0.1	39.7	0.1
10	Asante	1998	34	0.46	76.8	0.3	5.7	0.0
11	Nyayo	-	25	0.34	23.7	0.1	3.7	0.0
12	Acoustic	2017	22	0.30	263.3	0.9	9.3	0.0
13	Kenya Karibu	-	22	0.30	81.8	0.3	7.9	0.0
14	Komesha	-	22	0.30	320.7	1.1	9.1	0.0
15	Dutch Robijn	1960	19	0.26	2.45	0.0	2.7	0.0
16	Tigoni	1998	19	0.26	45.8	0.2	3.8	0.0
17	Kenya Mpya	2010	13	0.18	41.7	0.2	2.7	0.0
18	Destiny	2015	9	0.12	35.3	0.1	2.8	0.0
19	Nyota	2017	9	0.12	6.0	0.0	1.1	0.0
20	Kenya Dhamana	1988	6	0.08	45.6	0.2	2.8	0.0
21	Arizona	2013	5	0.07	6.5	0.0	0.6	0.0
22	Kenya Baraka	1973	5	0.07	78.5	0.3	3.2	0.0
23	Koberi	-	3	0.04	9.9	0.0	0.7	0.0
24	Manitou	2014	3	0.04	3.9	0.0	0.7	0.0
25	Derby	2014	2	0.03	3.5	0.0	0.4	0.0
26	Kenya Sifa	-	2	0.03	2.3	0.0	0.4	0.0
27	Ambition	2014	1	0.01	0	0.0	0.1	0.0
28	Challenger	2015	1	0.01	5.0	0.0	0.2	0.0
29	Desiree	1972	1	0.01	0	0.0	0.08	0.0
30	Farida	2018	1	0.01	0	0.0	0.008	0.0
31	Jelly	2014	1	0.01	0.2	0.0	0.05	0.0
32	Kenya Chaguo	1988	1	0.01	1.8	0.0	0.2	0.0
33	Kenya Mavuno	-	1	0.01	1.0	0.0	0.08	0.0
34	Konjo	-	1	0.01	0	0.0	0.2	0.0
35	Purple Gold	2010	1	0.01	0	0.0	0.02	0.0
36	Sagitta	2014	1	0.01	10.8	0.0	1.0	0.0
	Total		**7,412**	**100**	**29,112**	**100**	**56,499**	**100.0**

Figure 1A. Contribution of CIP Genebank to Wanjiku pedigree.



The International Potato Center (CIP) was founded in 1971 as a research-for-development organization with a focus on potato, sweetpotato and Andean roots and tubers. It delivers innovative science-based solutions to enhance access to affordable nutritious food, foster inclusive sustainable business and employment growth, and drive the climate resilience of root and tuber agri-food systems. Headquartered in Lima, Peru, CIP has a research presence in more than 20 countries in Africa, Asia and Latin America.

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