American Journal of Potato Research (2022) 99:217–228
https://doi.org/10.1007/s12230-022-09874-3

Economic Analysis of Alternative Ware Potato Storage Technologies in Uganda

Pieter Wauters[1,2] · Diego Naziri[3,4] · Alice Turinawe[5] · Regina Akello[5] · Monica L. Parker[6]

Accepted: 28 February 2022 / Published online: 30 March 2022

Abstract
In Uganda, potato is primarily grown as a cash crop and smallholder farmers sell majority of their produce immediately after harvest. Only a few farmers store ware potato for later sale using various traditional storage methods. Main reasons are farmers' immediate need for cash, the low volumes of potato harvested, fear of loss during storage due to pests and diseases, and a lack of adequate storage facilities. In order to exploit the seasonal market price fluctuations and increase the economic return of potato farming, improved individual and collective ambient ware potato storage units were introduced. Unlike traditional storage facilities that maintain the marketability of stored potato up to five weeks only, improved ambient stores can maintain their marketability up to nine weeks. This article uses cost-benefit analysis methods to compare the economic performance of improved ambient stores with traditional storage facilities. Results indicate that few of the traditional and improved collective storage units generated profit, an aspect that was attributed to management challenges. The improved individual stores performed overall well, generating higher profit margins than improved collective stores. Improved individual stores had an average payback period of three to four years that could even be reduced to less than one year if used at full capacity. Due to their characteristics, improved individual ambient ware potato stores thus seem to be particularly suitable to substantially increase the income of potato farming households.

Resumen
En Uganda, la papa se cultiva principalmente como cultivo comercial y los pequeños agricultores venden la mayoría de sus productos inmediatamente después de la cosecha. Solo unos cuantos agricultores almacenan papas para su posterior venta utilizando varios métodos de almacenamiento tradicionales. Las principales razones son la necesidad inmediata de efectivo de los agricultores, los bajos volúmenes de papa cosechada, el temor a la pérdida durante el almacenamiento debido a plagas y enfermedades, y la falta de instalaciones de almacenamiento adecuadas. Con el fin de explotar las fluctuaciones estacionales de los precios del mercado y aumentar el rendimiento económico del cultivo de papa, se introdujeron unidades mejoradas de almacenamiento de papa a temperatura ambiente individuales y colectivas. A diferencia de las instalaciones de almacenamiento tradicionales que mantienen la comerciabilidad de la papa almacenada hasta cinco semanas solamente, las tiendas ambientales mejoradas pueden mantener su comerciabilidad hasta nueve semanas. Este artículo utiliza métodos de análisis de costo-beneficio para comparar el comportamiento económico de las tiendas ambientales mejoradas con las instalaciones de almacenamiento tradicionales. Los resultados indican que pocas de las unidades de almacenamiento colectivo tradicionales y mejoradas generaron ganancias, un aspecto que se atribuyó a los desafíos de manejo. Las tiendas individuales mejoradas se desempeñaron en general bien, generando mayores márgenes de ganancia que las tiendas colectivas mejoradas. Las tiendas individuales mejoradas tenían un período de recuperación promedio de tres a cuatro años que incluso podría reducirse a menos de un año si se usaba a plena capacidad. Debido a sus características, las tiendas de papa ambientales mejoradas parecen ser particularmente adecuadas para aumentar sustancialmente los ingresos de los hogares productores de papa.

Keywords Cost-benefit analysis · Improved individual ambient store · Uganda · Ware potato storage

✉ Pieter Wauters
P.Wauters@cgiar.org

[1] International Potato Center (CIP), Kampala, Uganda

[2] Centre for International Migration and Development (CIM), Eschborn, Germany

[3] International Potato Center (CIP), Hanoi, Vietnam

[4] Natural Resources Institute (NRI), University of Greenwich, Chatham Maritime, UK

[5] Department of Agribusiness and Natural Resource Economics, College of Agricultural and Environmental Sciences, Makerere University, Kampala, Uganda

[6] International Potato Center (CIP), Nairobi, Kenya

Introduction

Potato (*Solanum tuberosum L.*) is a key food and cash crop in Uganda. The crop is traditionally grown by smallholder farmers in the southwestern, western, and eastern highlands of the country. Production recently expanded to low- and midland areas in central and northwestern Uganda. Owing to the bimodal rainfall pattern in Uganda, March–July and September–January are the major growing periods, although some off-season production also occurs in swamps, valley bottoms and irrigated areas (Okoboi 2011; Okwadi 2013). Uganda's national potato production has steadily grown over time to respond to an increasing market demand, mainly driven by population growth and rapid urbanization (Sebatta et al. 2015). National production was estimated at 181,904 metric tons (t) in 2019 (FAOSTAT 2019). This increase in production has been mostly achieved by expanding the land allocated to potato rather than by increasing productivity (Tindimubona et al. 2014). Limited use of improved inputs, pest and disease pressure as well as poor agronomic practices by farmers lead to yields of 3–7.5 t/ha, much lower than the achievable yields of 20–30 t/ha (Ferris et al. 2001; Aheisibwe et al. 2015; Arinaitwe et al. 2016; NARO 2017; UBOS 2020).

According to Kaguongo et al. (2008), potato farmers in southwestern Uganda sell the majority (62%) of their production immediately after harvest while the remainder is stored primarily as ware potato for food at home (18%) or as seed (19%) for the next cropping season. Storing potato as ware potato for later sale is rarely practiced. Middlemen market the produce directly without prior storage as well. Tatwangire and Nabukeera (2017) report that farming households in eastern Uganda market most of their potatoes (78%) directly after harvest, whereas 7% is consumed at home as ware potato and 15% is used as seed. Lack of ware potato storage for later sale results in seasonal mismatches between potato demand and supply leading to high price fluctuations that negatively affect most actors along the Ugandan potato value chain, particularly when the supply exceeds demand (Fig. 1).

Potato is a semi-perishable crop; if stored properly, quality of tubers can be maintained for several months. Storage can help reduce price volatility by allowing the market supply to be more evenly distributed throughout the year (Fuglie 1999). Key, however, is to maintain at an economical cost a sufficient quantity of tubers, of acceptable quality to the consumers, thus, to meet consumer demand (Wasukira et al. 2016). Variety, cultivation and harvesting practices, post-harvest handling as well as storage conditions and duration determine the storability of potato. Losses during storage comprise losses in weight and changes in chemical composition adversely affecting the quality (Eltawil et al. 2006). Although favorable storage conditions can limit excessive loss of moisture, sprouting, development of rots, and accumulation of sugars resulting in dark-colored processed products, storage losses cannot be completely avoided (Eltawil 2003). However, they can be reduced to a minimum by using a dark, well-ventilated environment with high relative humidity (95% or more) and, depending on the outlet, a temperature range of 5 to 10 °C (Rastovski 1981).

While advanced ware potato storage methods like evaporative cool storage and cold storage exist, they are not used in Uganda. Different authors reported the use only of rudimentary storage methods of mainly home-consumed ware potato by Ugandan potato farmers and other value chain actors. They include the floor or corner in houses, dark stores, stores that allow light to pass through (light stores), cribs made from local materials, wooden purlins, covering potato tubers deep in the soil, stacking tubers in sacks covered with tarpaulin, and heaping potato tubers under the tree shades. Majority of the current storage practices seems to be not very effective, and they allow keeping potato tubers in good quality for a short period of 2–5 weeks only, depending on the potato variety (Tatwangire and Nabukeera 2017; IFDC 2017).

To promote good storage practices in Uganda, improved individual and collective ambient ware potato stores were designed by the International Potato Center (CIP) and introduced in 2015 by CIP, Buginyanya Zonal Agricultural Research and Development Center (BugiZARDI) and the International Fertilizer Development Center (IFDC) at altitudes ranging from 1200 to 2300 m above sea level (masl). Both types of stores are dark, made of locally available materials and allow storage at ambient temperature by taking advantage of the cool air at night. Studies have shown that potato stored in improved ambient stores at high altitudes maintain quality and consumer acceptability for at least 9 weeks (Senkumba et al. 2017). Both technologies are well adapted to the context of smallholder farmers, and it is expected that their owners will be able to increase their economic return on potato farming by exploiting the seasonal market price fluctuations. Evidence on their profitability, however, is lacking. Therefore, the focus of this study was to assess the economic performance of the improved ambient stores in Uganda and compare with the traditional storage facilities used by Ugandan farmers to store ware potato for later sale.

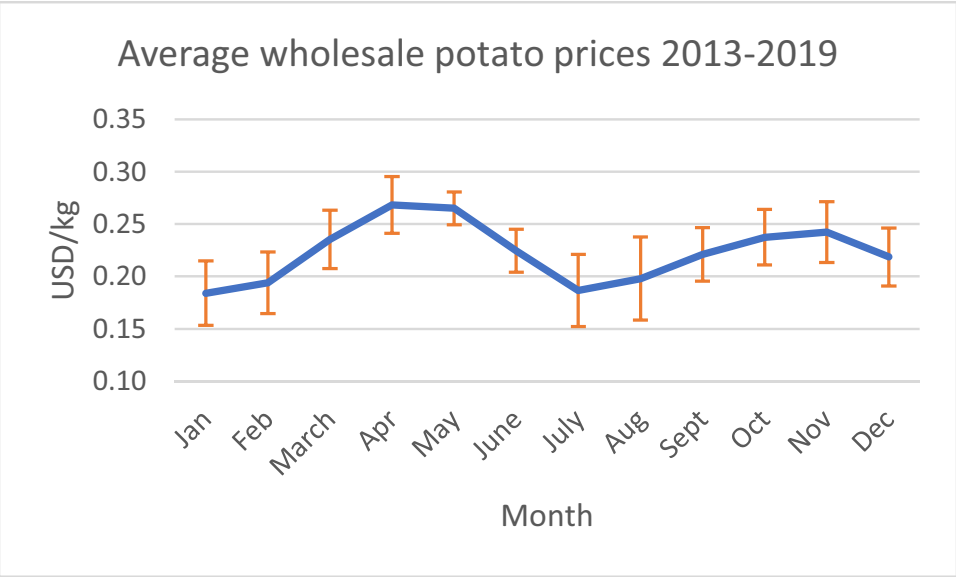

Fig. 1 Seasonal fluctuation of average monthly wholesale potato prices at four major markets (Kampala-Owino, Kabale, Mbale, Kapchorwa) in Uganda for the period 2013–2019 (own analysis based on data from Farmgain Africa 2019)

Materials and Methods

This study was conducted in the highland areas of eastern and southwestern Uganda. Both areas, which lie between 1500 and 3000 masl, are the major potato producing zones of the country due to their deep volcanic soils, mild temperatures, abundant rainfall, and reduced risk of disease. Although some off-season production occurs in swamps, valley bottoms and irrigated areas, March–July (season A) and September–January (season B) are the two major potato growing seasons (Ferris et al. 2001; Okoboi 2011; Okwadi 2013; Tatwangire and Nabukeera 2017).

Improved individual ambient ware potato stores have a length, width, and height of 5, 4, and 3.5 m, respectively, and their storage capacity is 8 t each. The construction costs are approximately USD 1100 and their estimated lifespan is 10 years. The construction materials are strong wooden poles, timber, corrugated iron sheets, a rat proof metal netting on the floor, and papyrus mats to minimize light entering the stores. A ventilation window facing the common wind direction is placed at the roof's top corner of each store. It is opened during the night to let out warmer air from the store and closed during the day to retain the cool night air in the store. Relative humidity is managed by placing buckets of water on the floor (Table 1) (Wasukira et al. 2017). Eleven individual ambient stores were piloted in the districts of Kween, Kapchorwa and Mbale in eastern Uganda. Ten of them were in use and managed by individual male and female potato farmers who have previously received training on good pre-harvest, post-harvest and store management practices (Fig. 2aand b).

Improved collective ambient ware potato stores have each a storage capacity of 50 t and an expected lifespan of 10 years. The costs of construction are approximately USD

Table 1 Overview of the specifications of improved ambient ware potato stores piloted in Uganda (Wasukira et al. 2017)

Specifications	Individual store	Collective store
Cost of construction (USD)	1100	15,000
Size (L*W*H) (in meters)	5×4×3.5	18×7×5
Storage capacity (t)	8	50
Estimated lifespan (years)	10	10
Construction materials	Strong wooden poles, timber walls, roof of corrugated iron sheets, rat proof metal netting on the floor made of timber struts, inside walls covered with papyrus mats to minimize light entering the stores	Reinforced gabion foundation, metal super structure, floor made of timber struts, compressed straw bales, cement walls covering the straw, corrugated iron roof on timber poles and covering the whole structure
Control measures of inside storage conditions	Ventilation window facing the common direction of the wind, bucket with water	Wind vent fitted at the corner opposite the door, bucket with water

Fig. 2 **a** Improved individual ambient ware potato store (view from outside). Credit: (CIP/P. Wauters). **b** Improved individual ambient ware potato store (view from inside). Credit: (CIP/P. Wauters)

Fig. 3 **a** Improved collective ambient ware potato store (view from outside). Credit: (CIP/P. Wauters). **b** Improved collective ambient ware potato store (view from inside). Credit: (CIP/P. Wauters)

15,000. They contain a metal super structure, sitting on a reinforced gabion foundation and supporting timber strut frames and straw bales. Cement walls covering the straw protect them from damage by rodents and bad weather. A corrugated iron roof on a timber pole frame covers the whole structure to create shade. Ventilation control is enhanced by fitting a wind vent at the corner opposite the entrance door. Like the ventilation window in an improved individual ambient store, the wind vent is closed during the day to retain the cool night air inside the store and opened during the night to release the warm air out of the store. Again, relative humidity is managed by placing buckets of water on the floor (Table 1) (Wasukira et al. 2017). Seven collective ambient stores were constructed in Kisoro, Kanungu and Rubanda districts in southwestern Uganda and Kween, Kapchorwa and Mbale districts in eastern Uganda. Two of them, however, were not properly constructed and collapsed completely. For this reason, only five were still usable and managed by farmer or trader groups whose members have previously been trained on good pre-harvest, post-harvest and store management practices (Fig. 3a and b).

To determine the economic performance of the improved ambient ware potato stores piloted in Uganda, record keeping templates were used to collect data on volumes stored and losses during storage, storage duration as well as costs and income related to ware potato stored for later sale. Data on the seasons 2018 B and 2019 A were obtained directly from farmers, farmer groups, or trader groups autonomously managing the stores, therefore, reflecting their own decision-making. Furthermore, approximately 10 members (five storing and five not storing potato in the group facility) were randomly selected from each of the five groups managing a collective store and interviewed using a pre-tested

structured questionnaire. A total of 54 potato farmers and traders were surveyed, and the collected data included group store management practices. To get qualitative feedback on the obtained research results, sex-disaggregated focus group discussions were organized with all five farmer and trader groups.

To determine the economic performance of traditional storage facilities currently used by Ugandan farmers to store ware potato for later sale, 240 farmers were interviewed in February–March 2019 using a pre-tested structured questionnaire. Within the study area, the districts, sub-counties, and parishes were selected using purposive sampling methods. Kween, Kapchorwa and Mbale in eastern Uganda and Kisoro, Rubanda and Kanungu in southwestern Uganda were the selected districts because of the presence of improved ambient ware potato stores. Information obtained from government extension workers on the local level of potato production and marketing was the basis for the selection of sub-counties and parishes. Villages were selected randomly within each selected parish, however, those villages with improved ambient stores were excluded from the sampling list. Also, pre-established lists of male-headed and female-headed households living in each selected village were used to randomly select the individual farmers to be interviewed. A total of 154 male and 86 female household heads were interviewed. Data on the seasons 2017 B, 2018 A and the off-season between the two main seasons were collected. The collected data included socio-demographic characteristics of potato farmers, farmers' access to potato management advice and market information, potato storage practices, potato volumes stored and losses during storage, storage duration as well as costs and income related to ware potato stored for later sale. The feasibility of the sampled traditional storage facilities was based on their actual use for ware potato storage for later sale.

Descriptive statistics were used to analyze potato farmers' access to potato management advice and storage behavior. T-tests, and Chi Square tests were used to test for significance, distinguishing between the sex of the household heads. For comparative cost-benefit analysis of traditional and improved storage technologies, the feasibility of each storage technology was computed using the benefit-cost ratio (BCR) and the payback period (PBP).

The BCR of an investment is the ratio of the present value of benefits of that investment to the present value of costs over time. An investment is considered viable when its BCR ≥ 1, meaning that the benefits of that investment outweigh the costs, while an investment is not considered viable when its BCR < 1, meaning that its costs outweigh its benefits (IFAD 2015). The BCR is calculated as follows (Shively 2012):

$$\mathrm{BCR} = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t} + I_t} \quad (1)$$

where:

B_t the technology's benefits at time t, where t = 0, …, n years
C_t the technology's costs at time t, where t = 0, …, n years
n the economic lifespan of the storage technology
I_t the investment costs in the storage technology at time t, where t = 0, …, n years
r discount rate

The discount rate is the interest rate used to convert all future benefits and costs to their present values. The reason behind discounting is that the value of money today is not the same as that of tomorrow. To factor out inflation in the analysis, the BCR was calculated using a real discount rate of 7.18%, which was calculated using the following formula:

$$\text{Real discount rate} = \frac{\textit{Nominal discount rate} - \textit{inflation rate}}{1 + \textit{inflation rate}} \quad (2)$$

The nominal discount rate used was the Bank of Uganda Central Bank Rate of 2018 (10%) while the inflation rate applied was the average rate of 2018 in Uganda (2.63%) (Bank of Uganda 2019).

The PBP refers to the amount of time needed to recover the original investment cost. The shorter the PBP, the more attractive the investment because of the shorter time needed to reach the break-even point. The PBP is determined as follows:

$$\mathrm{PBP} = \frac{\textit{Initial invesment}}{\textit{Annual net cash inflow}} \quad (3)$$

Variables of focus for the cost-benefit analysis included investment costs, losses during storage due to spoilage and shrinking as well as prices and quantities of ware potato before and after storage. Gross profit from storage is the added value at time t. It was computed as $(P_t{*}Q_t) - (P_0{*}Q_0)$, whereby P_t and Q_t were price and quantity of ware potato after storage, and P_0 and Q_0 were price and quantity of ware potato at harvest time, when prices are lowest (Fuglie et al. 1997). Net profit from storage is gross profit minus all operating and non-operating expenses strictly related to the storage practice, which include store management, maintenance, and administration, marketing expenses as well as annual depreciation.

Table 2 Socio-economic characteristics of the sampled potato farmers using traditional storage practices

	Overall ($n=240$)	Male-headed households ($n=154$)	Female-headed households ($n=86$)	t-value
	Mean and Standard Error			
Age (years)	43.2 (1.0)	40.4 (1.1)	48.1 (1.6)	−3.888***
Education (years)	5.8 (0.3)	7.2 (0.3)	3.2 (0.3)	9.403***
Experience in potato farming (years)	15.4 (0.9)	13.5 (0.9)	19.0 (1.7)	−2.869***
Experience in potato storage (years)	13.6 (0.8)	11.9 (0.9)	16.5 (1.6)	−2.473**
Total land owned (ha)	0.9 (0.1)	1.1 (0.1)	0.7 (0.1)	3.221***
Total annual area under potato (ha)	0.5 (0.0)	0.5 (0.1)	0.4 (0.0)	2.234**
Total annual potato harvest (t)	5.4 (0.6)	6.4 (0.9)	3.7 (0.5)	2.659***
Annual potato yield (t/ha)	11.9 (1.0)	12.5 (0.7)	10.8 (1.0)	1.474
	Percentage			**χ^2-value**
Access to credit (yes)	60.0	60.4	59.3	0.027
Group membership (yes)	35.0	38.3	29.1	2.072

*Figures in parentheses represent standard errors, while *** and ** denote significance levels at 1% and 5%, respectively*

Table 3 Access to potato management advice and market information by the sampled potato farmers using traditional storage practices

	Overall (%) ($n=240$)	Male-headed households (%) ($n=154$)	Female-headed households (%) ($n=86$)	χ^2-value
Access to advice on ware potato production (yes)	35.4	46.1	16.3	21.460***
Access to advice on potato harvest and post-harvest handling (yes)	35.4	39.6	27.9	3.305*
Access to advice on potato storage (yes)	20.0	24.0	12.8	4.354**
Access to advice on potato marketing (yes)	20.4	21.4	18.6	0.271
Access to market information (yes)	72.1	74.7	67.4	1.435

****, ** and * denote significance levels at 1%, 5% and 10%, respectively*

Results

Table 2 summarizes the main socio-economic characteristics of the typical potato farmers in the study areas, i.e., farmers using traditional storage practices. With an average age of 48 years, female household heads were significantly ($p<0.01$) older than their male counterparts, who were on average 40 years old. Female household heads also had on average 19 and 16 years of experience in potato farming and storage, respectively. This is significantly ($p<0.01$ & $p<0.05$) longer than for the male household heads, who had on average 13 and 12 years of potato farming and storage experience, respectively. The latter, however, had on average significantly ($p<0.01$) more years of formal education (7 years) than their female counterparts (3 years). Moreover, male household heads owned on average significantly ($p<0.01$) more land (1 ha) than female household heads (0.7 ha) and produced annually significantly ($p<0.01$) more potato (6.4 t vs 3.7 t). No significant differences, however, were observed between the potato yields obtained by male and female household heads as well as their access to credit and membership to groups.

As shown in Table 3, only a minority of potato farmers in eastern and southwestern Uganda had access to advice on potato production, harvest and post-harvest handling, storage, and marketing. Moreover, significant differences between male and female household heads were observed on their access to advice on potato production ($p<0.01$), harvest and post-harvest handling ($p<0.1$) as well as storage ($p<0.05$). A possible explanation is that female household heads lived on average significantly further away ($p<0.1$) from the sub-county agricultural extension office than the male household heads. Also, female household heads have multiple responsibilities at home that could limit their access to advice on potato management. No significant differences, however, were observed between the potato yields obtained by farmers with and without access to advice on ware potato production. This is explainable since potato yields are also influenced by several other factors including seed quality, soil health and weather conditions. Most of the sampled potato farmers had access to potato market information.

Table 4 Purpose of potato storage by the sampled potato farmers using traditional storage practices

	Overall (%) ($n=240$)	Male-headed households (%) ($n=154$)	Female-headed households (%) ($n=86$)
Storage for food at home (yes)	93.8	92.2	96.5
Storage for seed for own planting (yes)	83.8	85.7	80.2
Storage for ware for gifts (yes)	18.3	18.2	18.6
Storage for seed for sale (yes)	5.8	5.8	5.8
Storage for ware for sale (yes)	2.9	3.9	1.2

Table 5 Main reason of not storing ware potato for later sale by the sampled potato farmers using traditional storage practices

	Overall (%) ($n=233$)	Male-headed households (%) ($n=148$)	Female-headed households (%) ($n=85$)	χ^2-value
Have to sell immediately to get money	45.1	49.3	37.7	2.974*
Not enough potato to store	27.0	18.9	41.2	13.558***
To avoid losses due to pests and diseases	10.3	12.2	7.1	1.522
Have no storage facility	9.9	10.8	8.2	0.403
To avoid losses due to shrinking	1.7	2.7	0.0	2.337
Not profitable	1.3	1.4	1.2	0.013
High market price	0.9	1.4	0.0	1.159
Potato not storable due to low quality	0.9	0.0	2.4	3.513*
Fear of theft	0.9	1.4	0.0	1.159
Store for ware potato is far	0.9	0.7	1.2	0.159
Don't know to store	0.4	0.7	0.0	0.577
Too difficult	0.4	0.7	0.0	0.577
Low demand after storage period	0.4	0.0	1.2	1.749

**** and * denote significance levels at 1% and 10%, respectively*

Table 4 shows the potato storage behavior of the surveyed farmers. Almost all of them (93.75%) stored potato as ware potato for food at home. A large majority (83.75%) also stored potato as seed for own planting during the next season. Storage of potato as ware potato for gifts (18.33%), seed potato for later sale (5.83%) and ware potato for later sale (2.92%) were less frequent. No significant difference on potato storage behavior were observed between male and female headed households. 'Have to sell immediately to get money', 'not enough potato to store' and 'to avoid losses due to pests and diseases' were in decreasing order of importance the main reasons why farmers in the study area did not store ware potato for later sale (Table 5). 'Not enough potato to store', however, was indicated significantly ($p<0.01$) more by female than male household heads as the main reason for not storing ware potato for later sale.

Only seven of the 240 surveyed potato farmers stored ware potato for later sale, and their economic performance is summarized in Table 6. Dark store, dark room in the house, light store, and light room in the house were the traditional storage facilities used. They were mostly made of wood, mud and iron sheets, and their storage capacity ranged from 800 to 8000 kg, with an average of 2700 kg. The individual investment cost for each traditional storage facility ranged from USD 91 to 482, with an average of USD 318. On average, 650 kg of potato were stored annually and kept for about two months before sale as ware potato. The average loss of potato during storage and the monthly operational cost per kg of stored potato were estimated at 15.6% and USD 0.021, respectively. Average market prices after storage were approximately 20% higher than those before storage. On average, ware potato storage for later sale in traditional storage facilities lead to an annual net loss of USD 33 per store. Only two of the seven traditional storage facilities had a BCR > 1 and were therefore profitable. The payback period of three traditional storage facilities was determined and it ranged from 2.9 to 109.2 years, with an average of 39.2 years.

Table 7 indicates the economic performance of the ten improved individual ambient ware potato stores currently in use. They were supposed to be used individually, however, half of them had more than one user. On average, 20,100 kg of potato were stored annually in each store. This is possible because some of the stores were emptied and refilled again several times during

Table 6 Economic performance of ware potato storage for later sale by the sampled potato farmers using traditional storage practices

No	Storage facility	District	Investment cost (USD)	Storage capacity store (kg)	Qty potato stored annually (kg)	Average storage duration (days)	Storage loss (%)	Operational cost/kg/month (USD)	Average price good potato after harvest (USD/kg)	Average price good potato after storage (USD/kg)	Gross profit/kg (USD)	Net profit/kg (USD)	Annual net profit (USD)	BCR	Payback period (years)
1	Light room in house	Kisoro	400	800	100	90	0.0	0.006	0.21	0.27	0.05	−0.43	−43	0.1	109.2
2	Light store	Rubanda	482	8000	100	30	0.0	0.085	0.27	0.27	0.00	−0.65	−65	0.0	–
3	Light store	Rubanda	135	5000	180	60	55.6	0.028	0.40	0.42	−0.21	−0.35	−62	−1.2	–
4	Dark room in house	Kapchorwa	400	2000	260	30	23.1	0.010	0.11	0.13	0.00	−0.19	−50	0.0	–
5	Light store	Kween	315	300	800	90	25.0	0.009	0.12	0.16	0.00	−0.07	−57	0.0	–
6	Light room in house	Mbale	400	1000	1300	60	0.0	0.006	0.17	0.24	0.07	0.02	26	1.1	5.5
7	Dark store	Mbale	91	2000	1800	90	5.6	0.004	0.16	0.20	0.03	0.01	21	1.5	2.9
Mean			318	2729	648.6	64.3	15.6	0.021	0.21	0.24	−0.01	−0.24	−33	0.2	39.2
Stdev			148	2787	676.4	27.0	20.7	0.030	0.10	0.09	0.09	0.25	39	0.8	60.6

the same storage season. The average potato storage duration before sale as ware potato was 38 days and the average loss during storage was estimated at 5.8%. The computed average monthly operational cost per kg of stored potato was USD 0.012. Average market prices after storage were approximately 70% higher than those at harvest time. This higher price increase compared to the traditional storage facilities is probably due to the better quality of the potato after storage. The average annual net profit generated was USD 1767 per store. Nine of the ten improved individual ambient ware potato stores had a BCR > 1 and were therefore profitable. The payback period of the stores ranged from 0.2 to 12.7 years, with an average of 3.3 years.

The economic performance of the five improved collective ambient stores managed by farmer (4) or trader (1) groups is shown in Table 8. The stores were used by a minority of the group members. On average, only 27% of them used the store. The quantity of potato stored annually in the collective stores ranged from 24,600 kg to 168,800 kg, with an average of 71,079 kg. Again, this is possible because some of the stores were emptied and refilled again several times during the same storage season. The average potato storage duration before sale as ware potato was approximately one month. The average loss during storage was estimated at 6.5% and the average monthly operational cost of stored potato was computed at USD 0.008 per kg. Average market prices after storage were approximately 50% higher than those at harvest time. The average annual net profit generated by all five improved collective ambient stores was USD 3227 per store. However, two of the stores worked at an annual net loss. Four of the five improved collective stores had a BCR < 1 and were therefore not profitable. The estimated payback period of four collective stores ranged from 0.8 to 19.2 years, with an average of 9.1 years.

Table 9 shows that, if used for two storage seasons a year at full capacity, while maintaining constant the average storage duration, storage loss, operational storage cost per kg stored and prices before and after storage, the profitability of improved ambient stores increases, leading to a significant reduction of the payback period. The payback period of an improved individual ambient store falls even below one year.

Discussion

This study assessed the economic performance of potato storage as ware potato for later sales based on three technologies currently available in Uganda: traditional storage facilities, improved individual ambient ware potato stores and improved collective ambient ware potato stores. Results show that Ugandan farmers who stored ware potato for later sales in traditional storage facilities generally did not make any profit. As a result of low volumes of stored potato, high storage losses and high operational costs, most of the traditional storage facilities had a BCR < 1, meaning that the

Table 7 Economic performance of the improved individual ambient ware potato stores in eastern Uganda

No	District	Gender store manager	# Users	Qty potato stored annually (kg)	Max installed capacity used (%)	Average storage duration (days)	Storage loss (%)	Operational cost/kg/month (USD)	Average price good potato after harvest (USD/kg)	Average price good potato after storage (USD/kg)	Gross profit/kg (USD)	Net profit/kg (USD)	Annual net profit (USD)	BCR	Payback period (years)
1	Kapchorwa	Male	1	4100	51.3	27.0	7.3	0.023	0.13	0.27	0.10	0.06	227	1.7	3.3
2	Kapchorwa	Female	1	4200	32.5	29.4	0.0	0.012	0.16	0.22	0.05	0.01	57	1.0	6.9
3	Kapchorwa	Male	1	4800	60.0	26.0	16.7	0.010	0.12	0.21	0.03	0.00	−15	0.6	12.7
4	Kapchorwa	Female	1	20,400	97.5	52.3	10.8	0.009	0.12	0.18	0.05	0.03	678	2.3	1.4
5	Kween	Male	13	33,100	143.8	39.9	0.6	0.006	0.14	0.24	0.09	0.08	2762	7.7	0.4
6	Kween	Female	8	42,700	186.3	32.8	6.1	0.007	0.11	0.25	0.14	0.13	5510	12.2	0.2
7	Kween	Male	10	67,800	275.0	28.5	10.9	0.008	0.11	0.24	0.11	0.11	7136	11.7	0.2
8	Mbale	Male	1	4670	58.4	80.1	2.4	0.013	0.11	0.23	0.09	0.03	146	1.3	4.4
9	Mbale	Female	3	8222	69.0	42.0	2.4	0.017	0.16	0.26	0.09	0.05	446	2.1	2.0
10	Mbale	Female	6	11,011	16.9	26.0	0.4	0.017	0.30	0.38	0.09	0.07	724	3.1	1.3
Mean			4.5	20,100	99.1	38.4	5.8	0.012	0.15	0.25	0.08	0.06	1767	4.4	3.3
Stdev			4.5	21,499	80.4	17.0	5.6	0.005	0.06	0.05	0.03	0.04	2559	4.5	3.9

Table 8 Economic performance of the improved collective ambient ware potato stores in eastern and southwestern Uganda

No	District	Type of group managing store	Group members using store (%)	Qty potato stored annually (kg)	Max installed capacity used (%)	Average storage duration (days)	Storage loss (%)	Operational cost/kg/month (USD)	Average price good potato after harvest (USD/kg)	Average price good potato after storage (USD/kg)	Gross profit/kg (USD)	Net profit/kg (USD)	Annual net profit (USD)	BCR	Payback period (years)
1	Kisoro	Farmers	26	103,000	33.6	15.4	1.4	0.001	0.29	0.29	0.00	−0.01	−1994	−0.2	–
2	Kapchorwa	Farmers	8	29,900	32.0	45.5	13.0	0.010	0.13	0.21	0.04	−0.02	−714	0.5	19.2
3	Kween	Farmers	63	168,800	88.0	29.6	8.2	0.010	0.13	0.25	0.13	0.11	18,159	5.5	0.8
4	Mbale	Traders	6	24,600	27.2	53.4	6.4	0.004	0.16	0.26	0.09	0.02	542	0.9	7.4
5	Mbale	Farmers	12	29,097	47.2	26.2	3.4	0.016	0.14	0.25	0.07	0.00	141	0.8	9.2
Mean			27	71,079	45.6	34.0	6.5	0.008	0.17	0.25	0.06	0.02	3227	1.5	9.1
Stdev			22	63,614	24.8	15.3	4.5	0.006	0.07	0.03	0.05	0.05	8404	2.3	7.6

Table 9 Economic analysis of improved ambient ware potato stores if used for two storage seasons a year at full capacity

Economic indicators	Individual ambient store	Collective ambient store
Gross profit (USD/kg)	0.09	0.08
Net profit (USD/kg)	0.07	0.05
Annual net profit (USD)	1139	5410
BCR	3.7	2.5
PBP (years)	0.9	2.2

costs outweighed the benefits. Compared to the traditional storage facilities, the volumes of potato stored in improved ambient stores were higher, while the storage losses and operational costs were lower. The improved collective stores, however, also did not perform very well either. Four of the five piloted stores had a BCR < 1 and only the remaining store performed well. The improved individual stores, however, were in general profitable with the vast majority of them having a BCR > 1 and a payback period ranging from a few months to a little more than 4 years.

Ugandan potato farmers are a heterogenous group showing significant differences between female and male headed households. As reported by Mbowa and Mwesigye (2016), Ugandan potato farmers were on average approximately 40 years old and had received primary education. Female household heads, however, were in general older but less educated than their male counterparts. Majority of the sampled female household heads were widows. This possibly explains their higher age and consequently greater experience in potato farming and storage compared to the male household heads.

Most of the sampled potato farmers had access to credit. This credit, however, was mainly obtained from informal farmer group-level credit sources with little capitalization and high interest rates. For this reason, such loans tend to be small and do not allow farmers to invest in new technologies (Sebatta et al. 2015; Mbowa and Mwesigye 2016). The average annual amount borrowed by the sampled potato farmers is USD 169, with male household heads borrowing significantly ($p < 0.05$) more than their female counterparts.

In line with previous findings of Sebatta et al. (2014), majority (65%) of the potato farmers surveyed in this study were not members of a farmer group or association. This likely affected their access to potato management advice and market information. Significant differences could be observed between the access to advice on ware potato production ($p < 0.01$), potato harvest and post-harvest handling ($p < 0.05$) as well as potato storage ($p < 0.01$) by farmers whether member of a group or not. Even though group membership was expected to increase farmers' access to market information, no significant differences were observed between group and non-group members. Access to potato management advice by Ugandan potato farmers, however, remains overall a big challenge. The survey results confirmed previous observations made by Kaguongo et al. (2008), with only a minority of farmers having access to such kind of advice. Peer-to-peer exchanges are key for knowledge sharing as approximately 60% of the farmers having access to potato management advice had fellow farmers, family members or farmer groups as main source of advice. Moreover, the potato management advice given tends to focus more on aspects related to potato production and harvest and post-harvest handling, while less attention is given to good potato storage and marketing practices.

Potato yields obtained by female and male household heads were similar. They were greater than described in the literature but still only a half to a third of the achievable yield of 20–30 t/ha (Ferris et al. 2001; Aheisibwe et al. 2015; Arinaitwe et al. 2016; NARO 2017; UBOS 2020). This can be explained by the fact that majority of the sampled potato farmers stored potato as seed for the next cropping season. As reported by Gildemacher et al. (2009), the local seed chain, where potato farmers select, acquire, or buy informally seed saved from the previous season, offers an important service to Ugandan potato producers. Such recycled seed, however, is often characterized by poor health status due to latent infections by bacterial wilt, viruses and other tuber-borne diseases and leads consequently to low yields (Aheisibwe et al. 2015).

Results of this study revealed that female household heads owned on average significantly less land than male household heads. This possibly explains why the former planted annually significantly less land with potato than the latter, resulting into significant differences in the volume of potato harvested. This is likely the reason why significantly more female household heads reported not to have enough potato to store for later sale compared to their male counterparts.

Overall, Ugandan potato farmers do not store ware potato for later sale. About a half and a third of the sampled male and female household heads, respectively, did not store due to their immediate need for cash. Kaguongo et al. (2008) reported that crop sale is the main source of income for potato producing farmers in southwestern Uganda. This observation, combined with the fact that the loans obtained by potato farmers are rather small, limits their room to manoeuvre and forces them to sell potato immediately after harvest to cover the household expenses. Other important reasons why potato farmers did not store ware potato for later sale were in decreasing order of importance their fear of losses during storage due to pests and diseases and their lack of storage facilities. Almost all the sampled potato farmers, however, stored ware potato for later consumption within the household. This result confirms the role of potato as an important food crop in the Ugandan highlands.

The few sampled potato farmers who stored ware potato for later sale used principally traditional light storage facilities. These, however, are suitable only for storing seed potato because light promotes sprouting. Together with the longer storage duration, this possibly explains why the losses during storage in the traditional storage facilities (15.6%) were on average higher than those in the improved individual (5.8%) and collective (6.5%) ambient stores. Furthermore, with an average storage capacity of 2.7 t, the traditional storage facilities were smaller than the improved individual and collective stores with a storage capacity of 8 and 50 t, respectively. As a result, the average quantity of potato stored annually increased from traditional storage facilities to improved individual and collective ambient stores. Also, for all three storage technologies studied, the operational storage cost per kg potato stored tended to decrease with increased volumes stored. Therefore, the average monthly operational storage cost per kg potato stored was higher for the traditional storage facilities (USD 0.021) compared to the improved individual (USD 0.012) and collective ones (USD 0.006). Due to the combined effect of small volumes of potato stored, high losses during storage, high unit operational storage costs and relatively small differences between the prices after harvest and after storage, the traditional storage facilities had overall a BCR < 1 and were therefore not profitable. Improved individual ambient ware potato stores, however, performed very well as reflected by the good profits and relatively short payback period of 3–4 years. Furthermore, they are easy to maintain and can be shared on an informal basis with other potato farmers within the community to increase the use of the installed storage capacity. The improved collective ambient stores were overall also profitable for the owners but gave rise to several challenges typical of collective action endeavors, such as ensuring good maintenance of the store; low net cash flow returning to the group; and unequal participation of group members leading to low use of the installed storage capacity. Additionally, power imbalance resulted in the bulk of stored potato belonging only to a few influential group members, primarily men. These challenges resulted in four out of the five collective stores not being profitable (BCR < 1), with only one being economically viable (BCR > 1).

This study confirms that potato farmers in the highlands of eastern and southwestern Uganda are mainly smallholder farmers with low productivity. Our findings also show that majority of them store potato as food for later household consumption and as seed for next season planting. In general, Ugandan farmers do not store ware potato for later sale, mainly because of their immediate need for cash, the low volumes of potato harvested, fear of loss during storage due to pests and diseases, and a lack of adequate storage facilities. The few farmers who store ware potato for later sale use traditional storage facilities and, by doing so, actually incur economic loss. Improved individual ambient ware potato stores, however, are suitable to substantially increase the income of Ugandan smallholder potato farming households. They allow proper storage of potato, they can be shared informally with other farmers within the community, therefore avoiding formal group management challenges, and they are relatively inexpensive, easy to maintain and highly profitable – especially when used at full capacity. Based on our findings, it is recommended that local government extension services, development practitioners and international development partners collaborate to raise the awareness and build the capacities of potato farmers on good ware potato production, post-harvest handling and storage practices, including setting up demonstration of improved storage facilities built with locally available materials and providing evidence of their profitability under real conditions. Potato farmers' limited financial capacity and cash flow constraints can hinder their ability to build and extensively use improved stores. Given the lack of value chain financing, these challenges could be tackled by diversifying the sources of farmers' livelihoods and engaging microfinance institutions for the provision of affordable short-term loans to cover the household expenses for the potato storage duration and, hence, to defer the sale of ware potato and fetch higher prices. These institutions should also provide farmers with adequate and accessible finance that would allow them to invest in the construction of improved individual ambient ware potato stores. Furthermore, to increase the farmers' bargaining power, organizational models combining improved individual ambient ware potato stores with collective marketing initiatives should be explored. While adoption at scale of improved individual ambient ware potato stores has the potential to increase the income of potato farmers, it is unlikely that they will significantly stabilize national potato supply and reduce price volatility as this would require large-scale modern storage facilities and adoption of other supply chain management practices.

Acknowledgements This study was supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH commissioned by the Government of the Federal Republic of Germany under the project "Piloting seed potato production using rooted transplants of apical cuttings and assessment of the existing experiences of ambient ware potato storage in Uganda" (Grant Agreement No. 81229720). The authors would also like to acknowledge the support from the CGIAR Research Program on Roots, Tubers and Bananas (RTB), the Centre for International Migration and Development (CIM) as well as the Ugandan farmers and traders managing ware potato stores and who made their operational data available for analysis. We are also grateful for the feedback received by participants to the Tropentag 2021 Conference and the 14th Symposium of the International Society for Tropical Root Crops-Africa Branch where preliminary findings have been presented. All data were collected in compliance with the current laws of Uganda.

Author Contributions All authors contributed to the study conception and design. Material preparation, data collection and analysis were

performed by Pieter Wauters and Regina Akello. The first draft of the manuscript was written by Pieter Wauters and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability Statement The data presented in this study are openly available in [Dataverse] at [https://doi.org/10.21223/D0NMUS], reference number [UNF:6:2zDxcdrxInBTlbt4XSltnA==] and [https://doi.org/10.21223/UWXEQB], reference number [UNF:6:Frtywy3gojeWhOyamMfsug==].

Declarations

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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