Returns to improved storage and potential impacts on household food security and income: evidence from Tanzania

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Abstract:

This study examines the economic feasibility of improved storages and the potential impacts of using them on household food security and income. Moreover, it tests whether storage losses can induce early sale of households’ maize produce. We used data from on-farm experiment, household survey, and secondary sources. We considered Purdue Improved Crop Storage (PICS) bags, metallic silos, and polypropylene bags (control). Results show that PICS bags are profitable when the grain is sold during the lean season. However, the economic feasibility of metallic silos depends on the size of the storages and location i.e. silos of 1.5t and 2t storage capacities are feasible in some districts while lower size silos are not feasible in all locations. Storing maize using PICS bags will enhance household food security, especially among net-buyer farm households enabling them to reduce their annual grain deficit period by three to four weeks. Moreover, market-oriented storage using the improved storage options can increase farmers’ income substantially. Our results do not justify that the “sell low, buy high” situation observed among smallholder farmers is caused by high grain losses due to storage insect pests. Keywords: Maize, PICS bags, metallic silos, price seasonality, potential impact, Tanzania

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JEL Codes: O33, C65
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Keywords: Maize, PICS bags, metallic silos, price seasonality, potential impact, Tanzania
JEL codes: O33, Q12

1. Introduction
Postharvest grain losses are substantially high among smallholder farmers in Sub-Saharan Africa (SSA). The losses vary among countries, crops, and between seasons while the average figure ranges from 20 – 40% (Abass et al 2014). This is because of the fact that the great majority of smallholder farmers in SSA use traditional postharvest management methods which are less effective in preventing postharvest grain losses. This high loss indicates the necessity of improving postharvest grain management to address the problem of household food insecurity in developing countries. The link between postharvest loss and household food security is highly important particularly when the extent of postharvest loss associated with staple crops like maize is substantial.

Meanwhile improved storage technologies have been tested for their effectiveness in reducing postharvest grain losses. Studies indicate that improved storage technologies such as hermetic storages and synthetic pesticides are effective in preventing storage pests (Williams et al 2017, De Groote et al 2013, Chigoverah, et al 2016). For instance, De Groote et al (2013) found that metal silos are very
effective in controlling maize weevils and the larger grain borer while Super grain (hermetic) bags can control insect pests very well. Similarly, Bauoa, et al (2014) found that Purdue Improved Crop Storage (PICS) bags can completely prevent maize from storage insect pests in West Africa.

Despite the availability of technical information on the improved storage technologies, little is known on their economic benefits and contributions to food security. Therefore, this study has been initiated to fill these research gaps. It addresses three main objectives. First, it quantifies the additional financial benefit which farmers will get if they keep their maize grain in improved storage facilities for later sale and the potential impact on income at household level. Second, the study assesses the potential impact of using improved storage to household food security. Third, it tests whether storage losses can induce early sale of part of the grain allocated for household consumption. In so doing, our study contributes to the explanation of the “sell low, buy high” situation observed among smallholder farm households.

2. Methods

2.1. The study areas

The study was conducted in Babati, Kongwa, and Kiteto districts of Tanzania. Babati and Kiteto districts are located in Manyara region and Kongwa district is located in Dodoma region (Figure 1). The districts are characterized by unimodal rainfall pattern. The growing season starts in December/January and ends in June/July. Crops cultivated in the areas include maize, sorghum, millet, and legumes such as cowpea and pigeon pea. Maize is the dominant crop and accounts for 38% and 61% of the total cultivated lands in Manyara and Dodoma regions (URT 2016). In terms of production, it accounts for about 40% in Dodoma and about 70% in Manyara. Legumes are grown mostly as intercrops with maize and other cereals.
About one-third of the total maize produced is marketed (URT 2016). District towns are the major marketing centers for farmers, but farmers also sell products in village markets. There is an international market for maize in Kibaigwa (Kongwa) which is accessed by neighboring countries (such as Malawi and Uganda). Another outward oriented market is located in Babati town. Farmers sell most of their crops immediately after harvest when prices are low. One of the reasons could be fear of grain damage due to lack of proper storage facilities. In fact, more than 75% of the farmers use polypropylene bags for storage while the remaining farmers use other traditional methods such as the granary (Kihenge) and plastic containers/tins which are not effective in protecting stored grains from insect damage (Abass et al 2014).
2.2. Data and methods of analysis

2.2.1. Analyzing returns to storage

We considered three storage types in our analysis namely: Purdue Improved Crop Storage (PICS) bags (hermetic), metallic silos (hermetic), and polypropylene (PP) bags (non-hermetic). The PICS bags and the PP bags are of 100kg storage capacities. However, we included four alternative storage sizes of metallic silos (0.5ton size, 1ton size, 1.5ton size, and 2ton size) as different sizes of silos are being promoted in Tanzania.

The return to storage is given by the following equation which is a modified version of the equation proposed by Jones et al (2014):

$$\begin{align*}
R &= \left[ (1+s)(1-v)(1-w)-1 \right] p_0 q_0 - c_v - c_d - r_1 \left[ \frac{r}{12} (p_0 q_0 + c_v) + k \right] \\
&= \left[ (1+s)(1-v)(1-w)-1 \right] p_0 q_0 - c_v - c_d - r_1 \left[ \frac{r}{12} (p_0 q_0 + c_v) + k \right] \\
\end{align*}$$

where $R$ is the monetary return to storage in USD per ton; $s$ is price seasonality; $v$ is the price discount due to grain damage by insect pests; $w$ is the dry weight loss of the stored grain; $c_v$ is variable cost of storage; $c_d$ is annual depreciation cost; $k$ is initial investment on storage; $p_0$ is grain price at harvest; $q_0$ is the quantity of grain available for storage after harvest; $t$ is duration of storage in months; and $r$ is the cost of acquiring capital or the opportunity cost of capital (OCC).

The cost of acquiring capital may vary depending on the time length of the investment. If $r$ is different for short term and long term investments, Equation 1 can be modified as:

$$\begin{align*}
R &= \left[ (1+s)(1-v)(1-w)-1 \right] p_0 q_0 - c_v - c_d - r_1 \left[ \frac{r}{12} (p_0 q_0 + c_v) + k \right] \\
&= \left[ (1+s)(1-v)(1-w)-1 \right] p_0 q_0 - c_v - c_d - r_1 \left[ \frac{r}{12} (p_0 q_0 + c_v) + k \right] \\
\end{align*}$$

where $r_1$ and $r_2$ are OCC of short term and long term investments, respectively.

Dry weight loss ($w$): The data of dry weight loss was obtained from an on-farm experiment conducted from October 2014 until May 2015 in Dodoma and Manyara regions. The experiment involved 20 farmers who are residents of four villages in three agro-ecologies. Farmers produce maize as a dominant crop in the selected villages. The grain used in the experiment was infested under natural conditions. The experiment ran for 30 weeks and data were collected on dry weight loss and grain damage, among others. Our analysis needed data for more than 30 weeks in some cases. In those cases, we made linear interpolation from the actual data.
Price discount \((v)\): Price discounts are estimated from grain damage data based on Compton et al (1998). Studies indicate that grain buyers in Africa show some tolerance before they seek price discount from the sellers. However, the tolerance level varies across time and increases as one goes from the harvest season through to the lean season (Kadjo et al 2016). Indeed, farmers are not so sensitive to quality deterioration due to insect damage particularly during the lean season and their tolerance level during a very scarce season goes up to 30%. We adopted a 5% tolerance level following Jones, et al (2014).

Opportunity cost of capital \((r)\): We used the lending interest rates as a proxy for OCC. The assumption is that farmers would borrow money in order to save their maize and repay their debt later on taking the advantage of the expected higher revenue from maize during the lean season. This is particularly appropriate for those farmers who do not have enough cash deposit to cover expenses that may appear after harvest which forces them to sell their maize. The average bank lending rate in Tanzania was 14.2% for short-term loans (up to one year) and 16.1% for long-term loans (greater than one year) in the past three years (2014-2016) (BoT, 2015, 2016, 2017). We used both rates in our analysis depending on the duration of the costs\(^1\).

Price seasonality \((s)\)

The data used to estimate price seasonality are monthly average maize grain price data obtained from agriculture offices of the study districts. Our data cover January 2007-June 2017 in Babati, January 2006-May 2017 in Kongwa, and January 2006-June 2017 in Kiteto. All prices were measured in Tanzania Shillings and converted to US dollars equivalent using the average USD-TZS exchange rates corresponding to each month.

Farm gate prices are more appropriate in our analysis because we are considering on-farm storage while market prices include transport and market transaction costs which would result in overestimation of returns to storage. However, it is difficult to get such data as most farmers sell their crops in nearby markets. Moreover, it is difficult to find a formal structure that collect data at this level. One way to mitigate this problem is to estimate farm gate prices from market prices (World Bank 2009, Brooks et al 2007). According to World Bank (2009), farm gate prices are on average 63% of market prices in nearby towns in Tanzania. We use this estimation to construct data series for farm gate prices in our study.

\(^{1}\) For instance, the short-term rate was used to estimate the opportunity cost of the stored maize for months while the long-term rate was used to estimate the opportunity cost of a storage facility that was supposed to stay for more than a year.
areas. This wouldn’t have any impact on the estimation of the seasonal price gaps but it would be useful to mitigate potential overestimations on returns to storage.

The seasonal price gap, which is the difference between the maximum and the minimum prices, can be measured in different ways. One common approach is to estimate it from monthly dummies from a regression on trend adjusted prices of time series data (Gilbert et al 2017). This can be specified as follows:

$$\sum_{j=1}^{11} \delta_j Z_{mj} + \varepsilon_{ym}$$

where the trend $t = 12*(y - 1) + m$ and $Z_{mj}$ is the dummy variable defined by

$$Z_{mj} = \begin{cases} 1, & j = m \\ 0, & j \neq m \end{cases}$$

The seasonal factor is derived from the coefficient of the estimated equation using the following formula:

$$S_m = \delta_m - \frac{1}{12} \sum_{j=1}^{11} \delta_j , \quad (m=1, 2,..., 12)$$

While straight forward, this dummy variable approach usually leads to overestimated seasonal price gaps which will lead to wrong conclusions (Gilbert et al 2017). The bias would be serious particularly when the samples are short (5-15 years) and price seasonality is poorly defined because of some intervening factors. This problem can be mitigated by adopting parsimonious models such as trigonometric methods (Gilbert et al 2017; Kaminsky, et al 2016). Trigonometric approaches reduce upward bias in the estimated seasonal price gap by allowing larger number of observations to be used per parameter to be estimated.

If we assume a non-trending time series data, the trigonometric seasonality can be specified as the following two parameter sinusoidal equation.

$$S_m = \alpha \Delta \cos\left(\frac{m\pi}{6}\right) + \beta \Delta \sin\left(\frac{m\pi}{6}\right)$$
However, the absence of trend in food prices cannot be justified due to the fact that prices are non-stationary mainly due to inflation. Therefore, a model that takes into account non-stationarity of price time series would be more appropriate. The model with trending data is specified as follows:

\[ \Delta P_{ym} = \gamma + \alpha \Delta \cos \left( \frac{m \pi}{6} \right) + \beta \Delta \sin \left( \frac{m \pi}{6} \right) + u_{ym} \]  

(7)

Seasonal factors can be computed from a pure cosine function as follows:

\[ S_m = \lambda \cos \left( \frac{m \pi}{6} - \omega \right) \]  

(8)

where \( \lambda = \sqrt{\alpha^2 + \beta^2} \) and \( \omega = \tan^{-1} \left( \frac{\alpha}{\beta} \right) \)

The least square estimation of Equation 7 yields unbiased and consistent estimates as long as the specification is valid.

The trigonometric approach is more appropriate than the dummy variable approach to our analysis because it assumes that seasonality in prices arises from crop cycles and this is particularly relevant in the unimodal rainfall areas such as the ones we are considering in this study. Moreover, we have a small sample size (10 years for Babati and 11 years for Kongwa and Kiteto) and the trigonometric specification would enable us to use our limited data points efficiently in the estimation process. However, we juxtaposed the results of the trigonometric model and the dummy variable model for the sake of comparison (in the annex) although our discussion will be limited to the former to save space.

**Other considerations:** Return to storage is a function of duration of storage as grain prices and storage costs vary over time. To this effect, we computed returns to storage assuming that farmers would sell their maize in different months of a year. We also conducted sensitivity analysis by varying the values of selected variables namely OCC, storage price, maize price, and service life of the storage facilities. We varied OCC, storage price, and maize price by 20%, the service life of metallic silos by five years, and the service life of PICS bags by one year.

2.2.2. **Measuring potential impacts at household level**
Potential impact of using the improved storage practices were estimated based on data on the grain loss experiment and Tanzania Africa RISING baseline survey (TARBES). Impacts are assessed from two angles: from the food-security angle and from the income angle. We considered maize grain availability at household level for consumption to address the first and maize marketable surplus to address the second. Households were classified in to two categories i.e. surplus-producers and non-surplus-producers. We developed the categories based on households’ level of maize production as compared to the average maize consumption in Tanzania. We computed the average maize consumption based on FAO food consumption data\(^2\), Lukmanji et al. (2008), NBS and MFP (2016), and TARBES data which shows an average maize consumption of about 0.27kg/person/day\(^3\). Surplus producing (SP) households are self-sufficient in maize production all the time in a year while they also produce some surplus for sale. Households in this category have two main objectives to achieve i.e. optimizing household consumption from own maize stock (food security objective) and maximizing income from grain sale (income objective). Non-surplus producing (NSP) households are those households whose maize productions are less than or equal to their consumption requirements. Households in this category are considered as having a single objective of optimizing household maize consumption (i.e. food security objective). We considered both categories of households to assess the potential impact of improved storage from food security angle and considered only surplus producing households for the assessment with respect to income.

Effect on food security

We assume that farm households use part or all of their maize produces for consumption. Let \(C_0\) be the amount of maize a household allocates for consumption. This amount has to be stored and released in installments for consumption as consumption spreads over time. Let \(K\) be the consumption requirement of the household in one period. The amount of grain available in the storage would decline by \(K\) amount in each period such that \(f(t_0) > f(t_1) > ... > f(t_{n-1}) > f(t_n)\), and \(f(t_n) \equiv 0\). The series of household

\(^2\) [Link to FAO food consumption data]

\(^3\) This means that a kilogram of maize can be used for about 4 days for a person.

\(^4\) “\(n\)” implies the end of the year period for surplus producing households.
grain balance is \( f(t_1) = C_0 - K \), \( f(t_2) = C_0 - 2K \),... \( f(t_n) = C_0 - nK \). This can be easily generalized as \( f(t) = C_0 - tK \), where \( t = 1, 2, \ldots, n \).

Suppose that the grain is subject to storage loss due to insect pests and \( g(t) \) represents the marginal percentage of grain weight loss during the \( t \)-th period. The amount of loss at household level at the end of each period will be given by the pattern \( h(t_1) = (C_0 - K)g(t), \) \( h(t_2) = (C_0 - 2K)g(t_2), \ldots, \)
\( h(t_n) = (C_0 - nK)g(t_n). \)

Let \( k(t) \) be the cumulative distribution of the amount of grain loss at household level. If discrete distribution is assumed

\[
k(t) = \sum_{t=1}^{n} f(t)h(t), \quad (9a)
\]

and for a continuous time case,

\[
k(t) = \int_{t=1}^{n} f(t)h(t)dt = f(t)\int_{t=1}^{n} h(t)dt - \int_{t=1}^{n} f'(t)\left[ \int_{t=1}^{n} h(t)dt \right]dt \quad (9b)
\]

where \( f'(t) \) refers to the first derivative function of \( f(t) \).

\( f(t) \) and \( h(t) \) can be estimated from empirical data. We use Africa RISING baseline survey data to estimate \( f(t) \) and the loss experiment data to estimate \( h(t) \).

Equation (9a) (or Equation 9b) measures the effect of the improved storage on household grain availability for consumption. In other words, it shows the loss abatement effect of the improved storage. However, this effect is not without cost. Rather, it involves costs on the improved storages which would affect food security negatively. The latter effect is more visible particularly for net-buyer households as the additional cost of the improved storage would reduce their entitlement to food through purchasing.

Therefore, the net effect of the improved storage on food security will be the difference between its positive effect on food availability (loss abatement effect) and its adverse effect on food access. This can be presented as:

\[
F = k(t) - \frac{1}{p_0} (c_d + r_s k - c_0)
\]

(10)
F is households’ net food reserve and \( c_0 \) is the cost of the traditional storage while the other variables are as defined earlier.

Effect on income

The impact of improved storage on income has to do with households who have some surplus for sale. The effect on income arises from two sources. The first one is associated with the fact that improved storages will enable households to engage in temporal arbitrage of maize who otherwise would sell their crop immediately after harvest at low prices. We call this the temporal arbitrage effect. The second one is associated with their effect on the amount of marketable grain by avoiding loss due insect pests which is dubbed here as the loss abatement effect. Let \( M \) be the amount of grain which a household allocates for sale such that \( M \) and \( C \) (as defined above) add up to the total production. Consider households’ decisions with and without the storage. Suppose that a household allocates \( m_2 \) amount of grain for sale in the absence of the improved storage facilities and \( m_2 \) in the presence of the improved storage facilities. Further, assume that consumption gets priority to selling among households i.e. selling occurs when households’ consumption needs are met. In the absence of improved storage, households are expected to allocate more grain for consumption than they would do in the presence of improved storages due to expected grain loss in the former case. Thus, \( m_1 \) is greater than \( m_2 \). This implies also that the difference between \( m_1 \) and \( m_2 \) can be equated to \( k(t) \) (as defined above). Then, based on Equation 1 the total effect on household income \( (I) \) can be computed as:

\[
I = \psi p_0 [m_1 + k(t)] - c_v - c_d - r_1 \left[ \frac{1}{12} (p_0 (m_1 + k(t)) + c_v) + k \right]
\]

(11)

where \( \psi = (1 + s)(1 - v)(1 - w) \), for brevity.

By rearranging terms, Equation 11 can be put as

\[
I = \left[ \psi p_0 m_1 - c_v - c_d - r_1 \left( \frac{1}{12} p_0 m_1 + c_v \right) - r_2 k \right] + \left[ \psi p_0 k(t) - \frac{r_1}{12} p_0 k(t) \right]
\]

(12)

**2.2.3. Testing for the role of storage loss on the “sell low, buy high” puzzle**
We consider that the “sell low, buy high” phenomena arises when a farm household makes decisions to smoothen its intra-annual maize grain consumption. Let us assume that a household has decided to sell part of its maize grain, \( Y_s \), allocated for consumption in fear of potential storage loss, \( Y_l \). Suppose the household made this decision assuming that it will buy the same amount of grain from the market when the need arises. Suppose the household also knows, from past experiences, that it will pay higher prices to get the same amount of grain during the lean season. Under the assumption of rational choice, the following relationship will prevail:

\[
Y_s p_1 - Y_s p_0 (1 + r)^t \leq Y_l p_1
\]

where \( p_0 \) and \( p_1 \) are maize grain prices prevailing immediately after harvest and during the lean season, respectively.

Let \( p_1 = p_0 (1 + s) \), where \( s \) refers to the price seasonality factor as defined earlier, \( r \) is monthly discount factor and \( t \) is the number of months between the month of selling the grain and the month of buying it.

After a few algebra, we can arrive at the following relationship to test whether the “sell low, buy high” puzzle is driven by storage losses:

\[
\frac{Y_l}{Y_s} \geq 1 - \frac{(1 + r)^t}{s + 1}
\]

Equation 14 shows the case when transaction (marketing) costs are zero. However, it is not realistic to assume zero marketing costs and, hence, we need to include them in our analysis. In that case, Equation 13 becomes:

\[
Y_s p_1 - Y_s p_0 (1 + r)^t + C_s + C_b \leq Y_l p_1
\]

where \( C_s \) and \( C_b \) are costs of selling and re-buying the grain respectively.

Suppose that the cost of selling (buying) the grain is proportional to the value of the grain at the time of selling (buying). Let \( \delta \) and \( \gamma \) be coefficients showing the relationships during selling and buying the grain respectively. This will lead us to the following relationship:
\[ Y_s p_1 - Y_s p_0 (1 + r)^r + \delta Y_s p_0 (1 + r)^r + \gamma Y_s p_1 \leq Y_l p_l, \quad 0 < \delta < 1, \quad 0 < \gamma < 1. \]  \hspace{1cm} (16)

After some algebra, taking into account the relationship between \( p_0 \) and \( p_1 \) as defined earlier, we will arrive at the following relationship:

\[
\frac{Y_i}{Y_s} \geq \frac{s + 1 - (1 + r)^r + \delta(1 + r)^r + \gamma(s + 1)}{s + 1}
\]  \hspace{1cm} (17)

If we assume the coefficients of marketing are the same during selling and buying, Equation 17 will be reduced to the following equation:

\[
\frac{Y_i}{Y_s} \geq 1 - \left[ \frac{(1 - \delta)(1 + r)^r - \delta(s + 1)}{s + 1} \right]
\]  \hspace{1cm} (18)

We will use Equation 18 to test whether the “sell low, buy high” puzzle can be explained by storage losses. If the strict inequality in the equation holds true the “sell low, buy high” puzzle can be justified by the presence of storage losses whereas if the equality sign prevails, farmers become indifferent to take actions.

3. Results

3.1. Grain loss and damage

Figures 2 and 3 show that substantial grain weight loss and grain damage occur when PP bags are used for storage. The weight loss reached 71% within the storage period while the grain damage could go up to 100%. A similar study in Zimbabwe shows that damage can go up to 77% if maize is stored for 12 months which can be translated to high weight loss (Chigoverah, et al 2016). The weight loss and grain damage did not increase under the PICS bags and metallic silo storage options. Other studies also indicate that hermetic bags are highly effective in preventing main grain from storage pests such as weevils and large grain borer (Chigoverah, et al 2016, De Groote et al 2013).
3.2. Price analysis/seasonality

Figure 4 displays temporal price variations in the study areas. The plots indicate that the data are trending (are non-stationary) while they are potentially I(1) process. Moreover, the patterns in all cases show that the three locations are interconnected in terms of price movements. We tested the existence
of co-integration between each pair of locations using the Engle-Granger two steps method. We performed the Augmented Dickey-Fuller test for non-stationarity (unit-roots). We used the no-constant option in the ADF commend to suppress the constant term and used the lags (2) option to adjust for serial correlation.

![Figure 4: Monthly maize grain price in the study areas](image)

The results show that all the series are non-stationary and are the result of $I(1)$ process. Interestingly, the residuals corresponding to all bivariate combinations are $I(0)$ process implying that all location pairs are co-integrated. The ADF statistics show that co-integrations are statistically significant at 1% level. This shows that maize grain market in one location would respond to the situation in the markets of the other locations through the mechanism of spatial arbitrage resulting in price adjustments. It means, for instance, that when the average maize price in Kongwa is too high, it falls back to the average price in Kiteto plus a positive margin for spatial arbitrage between the two locations. These are expected given that the commercial centers of the three districts are not too far from each other. From the $z$ statistics in the ADF test, we can realize that the connection between Kongwa and Kiteto is the strongest (see
The seasonal gaps estimated based on the trigonometric model are displayed in Figure 5. The corresponding outputs of the linear model are found in the annex for comparison (A2 a-c). The model identified July as the lowest price month in all locations. This is consonant with the data we collected through key informant interviews. Seasonality is significant at 1% alpha level. It means that one cannot ignore the seasonal nature of maize grain supply in explaining price movements displayed in Figure 4. The seasonal gap varies between 32% and 55% depending on location. Kongwa is the place where the highest seasonal gap is observed and Babati the least (Figure 5). Kiteto lies in between but closer to Kongwa than to Babati.

![Figure 5: Estimated seasonal price gap](image)

3.3. Returns to storage

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5 The driving distances between commercial centers of Kongwa and Kiteto, Kongwa and Babati, and Kiteto and Babati are about 137km, 359km, and 255km respectively.

6 We conducted interviews with agricultural experts working in the areas. The data indicate that maize is harvested between mid-June and early September in Babati and between early June and late July in Kongwa and Kiteto. We thank Yangole Luhenda and Elirehema Swai for their support.
Figures 6 and 7 show the net returns to storages considering different months of the year for selling maize grain. Returns are negative if farmers sell their maize in the first two months after harvest (August and September) and in the last two months before the next harvest (May and June). This holds true for all locations and storage types. October to March is the feasible period for temporal arbitrage when PICS bags are used for storage in all locations. The highest return is obtained when the crop is sold in January. The length of the feasible period for PICS bags is longer by one month in Kongwa and Kiteto than in Babati. Metallic silos have shorter feasible periods than PICS bags. This is due to the high cost of silos as compared to PICS bags. The length of the feasible period of metallic silos varies by location and the size of the silo. The longest feasible period is associated with the 2ton silo in Kongwa (October-March) while the shortest one is associated with the 0.5ton silo in Kongwa (January). Metallic silos of sizes 0.5ton and 1ton are not feasible in Babati in any month. Polypropylene bags are not feasible in any of the three locations in any month.

![Figure 6: Returns to storage when PICS bags and PP bags are used](image.png)
The lean season in the study areas lies between November and March\textsuperscript{7}. This is the season when the supply of grain in the market gets low and the demand gets high resulting in high grain prices. Figure 8 shows the mean returns to storage associated with the lean season sales. The mean return to storage is about USD27/t for PICS bags. This is equivalent to 21\% of the monetary value of the stored grain which also means that farmers would gain about 2 bags of grain per ton when they use PICS bags. The mean returns are about USD6/t and USD9/t for metallic silo of 1.5t and 2t sizes. The mean returns are negative for metallic silos of 0.5t and 1t sizes; the losses are USD20/t and USD0.2/t, respectively. Polypropylene bags are associated with big losses as expected. The mean loss is about USD57/t which is higher than that of the least preferred metallic silo by about threefold.

The mean returns to storage (losses) for the lean season visibly vary across locations arising from variation in the temporal movements of maize grain prices. Babati is associated with the least mean figures for all storage types while Kongwa is associated with the highest. In the case of PICS bags, the

\textsuperscript{7} See figure A3 in the annex.
mean return to storage in Kongwa is about three fold of the return to storage in Babati while the mean return in Kiteto is about two fold of it. This shows that PICS bags are more attractive for investment in Kongwa and Kiteto than in Babati. The feasibility of metallic silos varies by location and by silo size. Returns monotonically increase with silo size. The 1.5ton and the 2ton silos can yield positive returns in Kongwa and Kiteto. In Kongwa, the 1ton size is also profitable. None of the silo sizes we considered in our analysis is associated with positive mean returns in Babati. As expected, using polypropylene bags would result in big negative returns in all locations the biggest value being associated with Babati.

![Figure 8: Mean returns to storage, lean season sale](image)

We conducted sensitivity analysis with respect to four selected variables (OCC, price of maize grain, price of the storage facilities, and service life of the storage facilities). The results are displayed in Figure 9 (panel a-d). The results show that changes in these variables will have substantial effects on the economic feasibility of the storages as revealed by changes in financial returns to storage. If OCC increases by 20%, silo15 and silo20 in Kiteto will be excluded from the feasible set of the base scenario and if it decreases by the same percent, silo15 and silo20 in Babat, silo5 in Kongwa, and silo10 in Kiteto will be added to the feasible set. The increase/decrease in OCC will also result in a decrease/increase of the average returns to storage in the feasible set by about 23%. Three cases will be added to the
feasible set if the price of maize increases by 20% i.e. silo5 in Kongwa, silo10 in Kiteto, and silo20 in Babati. Mean returns of the feasible set will also increase by 44%. If maize price decreases by the same percent, silo15 and silo20 in Kiteto will be out of the feasible set and the mean returns to storage will be reduced by 44%. Reduction of the price of the storage facilities will make silo5 profitable in Kongwa, silo15 and silo20 in Babati, and silo10 in Kiteto while increasing the prices will exclude silo15 and silo20 from the feasible set in Kiteto. No storage is added to the feasible set when storage service life is allowed to increase but the average return of the feasible set will increase by about 12%. However, a reduction of service life of the storages will create substantial change on the number and composition of the feasible set. In this case, PICS bags are no more feasible in Babati and Kiteto and silo15 and silo20 are no more feasible in Kiteto. The mean returns of the feasible set will also decrease by about 38%. In general, the most stable members of the feasible set are PICS bags, silo10, silo15, and silo20 in Kongwa. The average returns to storages of the most stable members of the feasible set range from USD13/t (when shorter storage service life is assumed) to USD31/t (when higher maize price is assumed). PICS bags in Babati and Kiteto are also stably feasible except when storage service life is reduced to one year.

![Diagram](image)

Figure 9: Sensitivity of returns to storage to changes in selected variables

Legend
- Storage types:
  - PICS = PICS bags
  - S5 = Metallic silo 5 bags size
  - S10 = Metallic silo 10 bags size
  - S15 = Metallic silo 15 bags size
  - S20 = Metallic silo 20 bags size
- Locations:
  - Babati
  - Kongwa
  - Kiteto
3.4. Potential impacts

We estimated the potential impact on food security based on the loss abated when the improved storage facilities are used whereas we estimated the impact on income based on the net returns obtained when grain sales are shifted from the harvest season to the lean season. Households are assumed to store grain for consumption and for market in the same facility should they see it feasible. This is particularly relevant for those who decide to use metallic silos due to its high fixed cost and that it may not be feasible for some households to have separate facilities for consumable grain and marketable grain. About 79% of the sample households are surplus producers while the remaining are either self-sufficient or net-buyers (i.e. non-surplus-producers). The mean amount of marketable surplus among surplus producers ranges from about 1.8ton in Kongwa to about 2.5ton in Kiteto with the mean figure of about 2ton. Non-surplus-producers produce, on average, 67% of their consumption requirements in Babati, 52% of their consumption requirements in Kongwa, and 72% of their consumption requirements in Kiteto.

Impact on food security

Smallholder farm households in the study areas produce maize for both home consumption and sale. Using improved storage facilities would affect the success in addressing these objectives of farm households by affecting the quantity (and quality) of available grain and the amount of income generated from crop sales. The most direct benefit of improved storages to smallholder farm households is their effect on the quantity (and quality) of grain available for consumption which was not captured by our analysis in Section 3.3. In this sub-section, we present the potential impact of the two improved storages (PICS bags and metallic silos) on food security at household level. Only the 0.5ton size silo is used in the analysis since the annual maize consumption requirements of the households are about 0.5ton and hence it doesn’t make sense particularly for the NSP households to own bigger size silos. The results are disaggregated by the two categories of households described earlier.

Results are displayed in Figure 10. The results show that PICS bags have positive impacts on households’ entitlement to food with some variation among household categories and locations. The net effect among the NSP households is about 43kg of grain which is sufficient for more than three weeks for household members. The net gain corresponding to the SP households is about 162kg which is
equivalent to 15 more food secure weeks. The net benefit of the NSP households from the improved storage is substantially low as compared to the benefits of the SP households. This is because of the low production of the households in the NSP category which would be consumed before storage pests cause substantial damage to the grain resulting in sub-optimal use of the improved storage. There is also slight difference among the three locations in terms of impact figures which is visible particularly when we consider NSP households. Indeed, the benefit among NSP households in Kongwa is marginal due to small quantity of maize produced by these households.

![Figure 10: Potential impact of improved storages on food security](image)

Metallic silos can save 13-32% of the grain which the farm households can use for home consumption. However, this positive contribution would be offset (or even overshadowed) by the high cost of the storage facility resulting in negative effects on food security among the NSP households. The mean net effects are marginal for SP households (i.e. about 16kgs) and negative for NSP households. Indeed, access to food would be reduced by about 12 weeks among NSP households if they purchase and use metallic silos for maize storage.

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8 SP households may sell the saved maize as they have enough amount of grain for consumption. In other words, this is the quantity of maize which could be reallocated from marketable grain to consumption if the polypropylene bags are used for storage.
Impact on income

Figure 11 displays the potential financial benefit of the sample households (surplus producers) if they participate in temporal arbitrage of maize by making use of PICS bags and metallic silos. It was assumed that, in the process of storage, farmers would combine different types and sizes of storages to maximize benefit. Such assumption is more plausible for the use of metallic silos which are less divisible to accommodate grains of smaller volume. The potential benefits vary by storage types and locations. PICS bags are associated with better benefits than silos of all sizes in all locations. Likewise, Kongwa is associated with the highest (lowest) potential benefit (loss) followed by Kiteto and Babati for all storage options we considered in the analysis.

PICS bags can yield positive benefits in all locations. The mean potential effect on income is about seven US dollars per person. Most of the impact is attributable to the temporal arbitrage effect of the storage (82%). Metallic silos have mixed effects on income depending on the size of the silo and the location of use. The potential benefit at mean level increase as silo size increases. Silos of 1ton size and above are associated with positive impacts on income in Kongwa and Kiteto. Impacts are mostly as a result of both temporal arbitrage and loss abatement effects of the storages. The exception is the case of 1ton silo in Kiteto where the positive impact is due to the loss abatement effect alone.

![Figure 11: Potential impact of using improved storages on income (USD/person)](image-url)
3.5. Does storage loss explain the “sell low, buy high” puzzle?

Our results show that the “sell low, buy high” decisions of farm households is not justifiable by storage loss. Considering an intermediate level of marketing cost\(^9\), the minimum thresholds for storage losses that induce “sell low, buy high” decision are 52% in Babati, 62% in Kongwa, and 60% in Kiteto while the storage loss using PP bags (the most widely used storage in the area which is conducive to storage pests) is about 33% if grains are stored till the end of the leanest month. However, our results support the null hypothesis (i.e. the “sell low, buy high” decision induced by storage losses) if marketing costs are zero. Given that marketing costs are usually positive, the results suggest that farm households would be better off if they keep their consumable maize in storage instead of selling it immediately after harvest and buying it later on during the lean season. While our finding does not justify “sell low and buy high” as a strategy of smoothening household maize grain consumption among farm households, it implies that farmers have other major reasons to make a seemingly ‘irrational’ decision with regards to staple crops in general and maize in particular. Studies indicate that massive sales of staple crops among smallholder farmers in SSA are induced mainly by liquidity constraints arising from various socioeconomic obligations during harvest and postharvest season (Stephens and Barrett 2011).

Figure 12 shows the interplay of three factors (expected price changes, expected storage losses, and expected marketing costs) which we considered in our analysis\(^10\). It shows that the higher the expected maize price increment the higher the required storage loss would be to induce the “sell low, buy high” decision among households. However, this depends on the level of marketing costs. Higher marketing costs would suppress the decisions of households to sell part of their maize immediately after harvest as a strategy of smoothening consumption through market mechanism.

\(^9\) The medium marketing cost is about 8000TZS per 100kg of marketed maize.

\(^10\) We could not include the fourth factor (i.e. discount rate) in the figure due to the limitation of graphical analysis (i.e. a maximum of three dimensions). However, it was considered to test the main hypothesis.
Temporal arbitrage in maize marketing is profitable for smallholders who produce some surplus for market if they use improved storage technologies. The mean return to storage for all locations is about 27USD/t for PICS bags which is equivalent to 21% of the monetary value of grain stored. The highest benefit is associated with Kongwa and the lowest with Babati. Metallic silos can yield positive financial returns depending on the size of the storage and location. Bigger silo sizes (particularly, the 1.5ton and the 2ton sizes) are profitable in Kongwa and Kiteto and hence they can be used as alternative storages to participate in temporal arbitrage of maize grain. However, our results do not justify the use of smaller silo types in Kongwa and Kiteto and all sizes of silos of we considered in this study in Babati given the prevailing storage costs and maize prices. In other words, some levels of subsidies are required to realize the adoption of smaller metallic silos in Kongwa and Kiteto and that of even larger metallic silos in Babati.

Using PICS bags instead of the PP bags can increase food access among non-surplus producing households by about three weeks while it increases maize market supply by about 162kg per surplus producing household. For the NSP households, the highest impact is expected in Babati due to better production and the lowest in Kongwa. However, Babati and Kongwa show comparable results in the

Figure 12: Interplay of factors for early grain sales
case of SP households while Kiteto takes the least position. PICS bags have also positive potential impacts on income of SP households. The mean effect for all locations is about seven US dollars per person which is mainly attributable to the temporal arbitrage effect of the storage facilities. The results suggest the promotion of PICS bags to enhance food security and income among farm households in the study areas.

Metallic silos have positive impacts on income in Kongwa and Kiteto given that bigger sizes (i.e. 1.5ton size and 2ton size) are used. However, our results do not justify positive potential impacts of smaller size silos on income in Kongwa and Kiteto and that of all sizes in Babati. Moreover, metallic silos have negative potential impact on household food security which is due to the high investment cost associated with these storage facilities.

Finally, we tested whether maize grain sales immediately after harvest is due to storage losses. However, we failed to accept the null hypothesis that storage loss would induce early sales of maize allocated for consumption. This implies any of the following conclusions: (1) farm households do not use “early-selling-and-late-buying” as a strategy of minimizing the impact of storage loss on consumption and that the households buying grain during the lean season are those who are not self-sufficient from the beginning; (2) There are other factors which induce early sales of grain among farm households. The first conclusion indicates the non-existence of the “sell low, buy high” puzzle while the second one associates the existence of the “puzzle” to factors other than storage loss. However, the validity of the second conclusion requires complementary studies in the future.

References


Lukmanji Z., Hertzmark E., Mlingi N., Assey V., Ndossi G., Fawzi W., (2008). Tanzania Food Composition Tables. Muhimbili University of Health and Allied Sciences (MUHAS), Tanzania Food and Nutrition Centre (TFNC), and Harvard School of Public Health (HSPH).


Apendix

Table A1: Z statistics in the ADF unit roots test for residuals

<table>
<thead>
<tr>
<th></th>
<th>Kongwa</th>
<th>Kiteto</th>
</tr>
</thead>
<tbody>
<tr>
<td>Babati</td>
<td>-3.196</td>
<td>-3.555</td>
</tr>
<tr>
<td>Kiteto</td>
<td>-4.571</td>
<td></td>
</tr>
</tbody>
</table>

All values are less than the critical values at 1% indicating that the residuals are I(0) process.

Figure A2-a: Estimated seasonal price movements in Babati using the trigonometric and the linear models
Figure A2-b: Estimated seasonal price movements in Kongwa using the trigonometric and the linear models

![Graph showing estimated seasonal price movements in Kongwa using the trigonometric and the linear models.]

Figure A2-c: Estimated seasonal price movements in Kiteto using the trigonometric and the linear models

![Graph showing estimated seasonal price movements in Kiteto using the trigonometric and the linear models.]

Figure A3: Lean season and other seasons in the study areas