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Deploying Zero-energy Technologies to Reduce PHL of Horticulture crops for improving Farmers' Economic Welfare in Tanzania

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Abstract

Tanzanian Fruits and Vegetables (F&V) industry employs more than 4.5 million people whose 70% are women and grew at 11% annually in the last decade. Despite the vital role played by F&V industry, the sub-sector experiences huge Post-Harvest Losses (PHL) accounting for up to 60% of the total produce. These losses threaten sustainability of the production, enlarge Food & nutrition insecurity concerns, deprive economic use of the produced crops, increase prices of crops and reduce amounts of consumer expenditure to reach farmers. This paper employed semi-systematic approach and content analysis to unveil potentials of using Zero Energy technologies to lessen PHL in Tanzania's F&V industry. Search queries namely; 'postharvest losses (PHL) management, Tanzania Fruits and Vegetables and Zero Energy technologies' were used to solicit literature from reliable bibliographic databases including Google scholar, JUSTOR and Science Direct. Results showed that a number of practices and technologies to handle F&V including manual harvesting, non-refrigerated transport modes; and traditional storage facilities such as bamboo baskets, plant leaves % open spaces under the shade. Deploying usage of ZECC to address PHL of F&V would lower food losses amounted to 2,093,583tons of fruits and 587,569 tons of vegetables per annum whose value amounts to 4.6 trillion and 1.4 trillion Tanzanian shillings respectively. The value of PHL for both fruits and vegetables (six trillion) were enough to pay annual public servants' salaries or the government annual debt by 87% in 2021/2022. Moreover, the spreading effect would enhance food and nutrition security, improve affordability of F&V to consumers and raise farmers' income. Indeed, reduction of PHL in the F&V industry will lead to economic empowerment of women involved in the F&V sub sector.

Keywords: *Post-harvest Losses, zero energy cooling technologies, Fruits and vegetables, Horticultural crops, Content analysis, Semi-systematic review approach, Tanzania*

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Introduction

Post-harvest loss (PHL) is still a global challenge to date despite the Sustainable Development Goal 12.3 that seeks to halve the losses along food value chains by 2030. It is estimated that one-third global food produced are lost/wasted before consumption (African Union Commission (AUC), 2018; WEF (World Economic Forum), 2020). Likewise, PHL in agri-food sector accounts for 30% of Africa's produce (World Bank (WB), 2020). The Africa PHL amounts to 100metric tons per annum which is equivalent to four billions USD (AUC, 2018). The annual African food losses would feed 48 million people; and surpass food aids received by Sub Saharan Africa (SSA) for the entire decade (AUC, 2018).

Tanzania's PHL amounts to 3.78million tons per annum that is relatively higher in horticultural sector (40%) compared to that of cereal produce (15%) (URT, 2021; URT, 2019). Some studies noted even higher rates of the losses accounting for 46% in the domestic markets (Ekka and Mjawa, 2020); while others estimated losses to ranges between 0-33% among different types of fruits and up to 35% for vegetables; while quality loss ranges between 0.5- 60% for vegetables and 5-80% for fruits traded (Kitinoja and Kader, 2015; URT, 2019; Plant 2015). The economic loss due to PHL for Tanzania's major food crops amounts to USD 541,700 per annum (***ibid***).

The PHL enlarges food insecurity challenge, puts more pressure on earth's non-expanding production resources, deprive economic use of the produced foods, increases produce' prices for consumers and reduces amount of consumer expenditure to reach farmers (Ridolfi *et al.*, 2018; Rockefeller Foundation, 2015). Actually, PHL reduces income of agrifood value chain actors through physical and quality losses. While physical loss denies the intended consumption and associated value along the chain, quality loss leads to low priced products or even thrown abandoning the whole value all together (Dome *et al.*, 2017). In Tanzania, Barber et al (2015) noted that farm gate price received by farmers accounts for 32% and 43% only of the retail price for fruits and vegetables respectively.

Technologies to handle PHL include refrigerated stores whose utilization is limited by huge operational costs that impair economic feasibility of F&V handling investments along the chain (Kamugisha *et al.*, 2017; Kitinoja *et al.*, 2019). Charcoal cooler utilization is demoted as it amplifies deforestation which harms the environment. Moreover, Pot in Pot Cooler (PPC) is relatively small in size that suits more household level where relatively small volumes of F&V are handled. The Zero Energy Cool Chamber (ZECC) has proved useful in elongating shelf life of F&V (Dirpan *et al.*, 2018; Majubwa and Mtui, 2022) and its application suits at retail stage since it can handle more volumes of the produce.

This paper advocates the use of Zero Energy Cool Chamber (ZECC) at retailing nodes to reduce PHL of F&V. Addressing the losses will improve economic status of about 4.5 million residents involved in the F&V supply chain (Ekka and Mjawa, 2020), enhances the national food & nutrition security attainment and mitigate climate change by reducing GHGs that would be emitted by producing more food.

Literature on PHL in the national horticultural sub-sector is widely documented. However, previous researches aligned their studies on estimation of losses incurred along the chain (Barber *et al.*, 2015; Dome and Prusty, 2017; HELVETAS, 2014; Kitinoja and Kader, 2015), determinants of the losses (Kulwijila, 2021), investment opportunities in the fruits and vegetables sub-sector (Maden *et al.*, 2021) and role of TAHA on reducing PHL in horticultural products (Ekka and Mjawa, 2020). To the knowledge of the author, only two studies on the use ZECC to address PHL in horticultural sub-sector exist in Tanzania (Majubwa and Mtui, 2022; Samwel, 2019). While Samwel (2019) focused on only one vegetable (tomatoes) in one region of the country named Morogoro; Majubwa and Mtui (2022)low cost technologies to reduce PHL on tomato only. This review paper complements the literature gap in PHL handling by advocating the use of ZECC in F&V at retailing node where PHL is relatively higher compared to other nodes of the chain in developing countries like Tanzania (Dome and Prusty, 2017; Sharma *et al.*, 2011; URT, 2019).

This paper is organized in five sections. Section one presents background information (problem setting) while section two provides methodology employed in the study. Section three presents results and discussion of the paper that include overview of efforts made by different stakeholders in addressing PHL, discussion of prevailing technological innovations of PHL handling in tropical countries like Tanzania, documented status of PHL, prevailing technologies and practices to handle F&V in the country Section and established real costs of PHL in the F&V industry. Section four brings out conclusion while section portrays recommendations.

Materials and Methods

Semi-systematic review approach was used to explore feasibility of addressing PHL of F&V at the retailing chain node from Science Direct, PubMed, Google Scholar and JUSTOR bibliographic databases; using the following search terms: 'Post-harvest losses', 'Fruits and Vegetables', 'Tanzania horticultural sub-sector', 'smallholder farmers', 'Zero Energy Cool Chamber' and 'Tanzania legislation framework on horticultural products'. Reviews were made on literature citations between 2010 and 2023. The screening was done by reading the title and abstract before the entire paper being reviewed. Patterns and trends of PHL in F&V were characterized by using content analysis approach.

Results and discussion

Initiatives to Reduce Post-Harvest Losses

Globally, lessening of PHL initiatives is seen in the United Nations Sustainable Development Goal (SDG) 12.3 that intends to halve per capita food losses & waste; and goal 2 whose target is to end hunger & food insecurity in the world by 2030. Ratification of SDGs in Africa was made through Malabo declaration of 2014 whereby Heads of States of African Union Commission committed their nations to halve PHL and end hunger by 2025. This is further supported by the devising of African Postharvest Losses Management Strategy in 2018 (African Union Commission [AUC], 2018). The strategy aims at enhancing implementation of Malabo Declaration of reducing PHL along agricultural value chains among member States in ten years' time period (2015 – 2025).

Post-harvest losses challenge in Tanzania can be traced back to early 1970s during the upset of Large Grain Boer (LGB) in the country that endangered national food security attainments. Since then various initiatives to maintain food security requirements have been undertaken by different stakeholders including the government, development partners and researchers.

The government has ratified global and regional initiatives by devising policies, regulations, strategies and number of programs. These include Tanzania Horticulture Development Strategy 2012 – 2021 (URT, 2021), National Agriculture Policy of 2013 (URT, 2013), Postharvest Management Strategy Implementation Plan 2019 – 2024 (URT, 2019) and National Horticulture Development Strategy and Action Plan 2021 – 2031 (URT, 2021). The National Agricultural Policy of 2013 acknowledges PHL as the national challenge that hampers food and nutrition security attainment. Meanwhile, the National Horticulture Development Strategy and Action Plan of 2021 – 2031 stipulates government commitment to promote usage of good handling practices and technologies to reduce PHL in horticultural crops.

Moreover, the government established Food Assistance Scheme of 1976 aimed to reduce food importation that necessitated existence of Strategic Grain Reserves (SGR). The SGR was housed under the Ministry of Agriculture and Food Security in the section of Food Security and National Milling Cooperation (NMC). Later on, reforms were made and vested food crops functions to the department of Food Security (FSD) whose task was to oversee agricultural issues related to the post-harvest management among others. It can be concluded that the government has made significant achievements to address PHL through different programs including construction of 450 warehouses countrywide that are able to store between 200 and 500 metric tons and 73 storage facilities storing up to 200 metric tons (URT, 2019), rehabilitation of regional post-harvest management centers; and supporting of institutions which provide farmers with trainings on reduction of PHL.

Development partners such as Food and Agricultural Organization (FAO) and United Nations Development Program (UNDP) collaborated with the government to construct farmers' storage facilities in the mid-1980s to fight PHL during invasion of LGB. The storage facilities built had the storage capacity of between

200 and 400 metric tons. The Sasakawa 2000 in collaboration with the government constructed 1,260 storage facilities to farmers with different storage capacities ranging between 200 and 400 metric tons. The Swiss Development Organisation (HELVETAS) implemented the PHL prevention project aiming at reducing PHL in Tanzania's grain foods. Moreover, Alliance for Green Revolution in Africa (AGRA) implemented the YieldWise Maize Project between 2015 and 2019 to reduce PHL and increase smallholder farmers' income by 25%.

Researchers including Sokoine University of Agriculture (SUA), University of Dar-es-Salaam, Small Industries Development Organisations (SIDO) and Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) have devised number of technologies to lessen PHL in the country. Actually, a number of them exist.

Prevailing Post-Harvest handling technologies

Numerous technologies to handle PHL exist. Refrigerated stores and Controlled Atmosphere Storage (CAS) are known for their efficiency in preserving and prolonging shelf life of fresh foods like F&V in tropical countries including Tanzania. However, the technologies entail the use of intensive capital to purchase; and expensive operational costs in their use (Bodbodak and Moshfeghifar, 2016; Kamugisha *et al.,* 2017; Kitinoja *et al.,* 2019)

Alternatively, the non-energy using technologies elongate shelf life for fresh foods and lessen PHL exist. These include evaporative charcoal cooler (ECC), Pot in Pot Cooler (PPC) and Zero Energy Cool Chamber (ZECC). The ECC is built with charcoal laden walls with wire mesh whose walls are watered to maintain the walls humid. This processing of watering charcoal walls enhances heat transfer from inside the cooler to ambient air (Ambuko *et al.,* 2017). The ECC has proved to lower temperature inside the cooler by 16.85 degrees and maintain the humidity difference by 38% within the cooler (Ronoh *et al.,* 2018; Ronoh *et al.,* 2020). Ronoh et al. (2018) noted that ECC extended shelf life of Amaranths from 2 days in the room temperature to 12 days in the cooler; and prolonged the shelf life of spinach from three days at room temperature to 12 days in the cooler. However, this technology is more practical in rural areas at farm level to maintain the newly harvested produce fresh. Moreover, the technology is limited by the fact that it promotes deforestation which harms the environment.

The PPC entails utilization of burnt clay pot with 65cm height and a wall of 8mm. In this case a small port is inserted in another pot which is bigger surrounded by a space of 7cm. The space between the pots is filled with sands that is watered frequently (Yahaya *et al.,* 2018). The PPC works by evaporation of water from sands surrounding the small pot and relatively high humidity levels in the ambient air. The PPC technology has proved useful in prolonging shelf life of chill papers from three days in room temperature to 18 days; and carrots & cabbages from 9 days up to 18 days (Verploegen *et al.,* 2019). However, application of the PPC is limited to be used at the household level where relatively low volumes of F&V are handled. The volumes handled at market places are relatively huge which needs more spacious structures to handle large volumes of F&V.

ZECC is built by stacked bricks and a space between the bricks is filled with sand that is saturated with water. The ZECC prolong shelf life of agricultural fresh produce by lowering temperature and preserve high humidity levels within the chamber (Singh *et al.,* 2010). Low temperature and higher humidity levels within the chamber depress metabolic processes and weight loss of the produce. Kamal and Pandey (2018) noted that ZECC prolongs shelf life of leafy vegetables and tomatoes from three days at room temperature to 12 days during the winter season. Other scholars also found that ZECC has been proved to work efficiently in reducing post-harvest losses for horticultural crops in Indonesia (Dirpan *et al.,* 2018) and in India (Kumar *et al.,* 2018). In Tanzania, Samwel (2019) found promising usefulness of ZECC that it increased shelf life of tomatoes whereby only 5% deteriorated in 12 days period. Therefore ZECC is sought to save as low-cost cool storage facility in developing countries like Tanzania. Therefore, this paper advocates up scaling the use of ZECC structures at retail markets of F&V where massive PHL occurs in Tanzanian context (Dome and Prusty, 2017).

The status of Tanzania PHL for fruits and vegetables

Tanzania's PHL in F&V accounts for significant proportion of the produce ranging between 7% and 50% across crops (Table 1). The loss amounts to USD 541,700 per annum (URT, 2019). Oranges depicts a smallest proportion of PHL accounting for only 7.6% of the marketed produce (Mgonja and Utou, 2017). The low proportion of PHL in orange can be associated with relatively longer shelf life of up to 14 days compared to other F&V with less than 10 days at room temperature. Causes of PHL include decaying as a means of metabolic processes, rodents, heavy rainfall during harvesting periods and poor roofing materials (HELVETAS, 2014; Kulwijila, 2021). The most proportion of PHL was recorded at retailing mode (Msogoya and Kimaro, 2011; Mwagike and Mdoe, 2015; URT, 2019). The huge proportion of F&V lost after harvest is a wake-up call for government and other stakeholders to intervene in improvement of F&V handling at marketing stage. Some authors have documented lack of central storage facility at retailing nodes as a prerequisite step in lessening the PHL in fruits and vegetables (Dome and Prusty, 2017; Issa *et al.*, 2021).

Tables

Table 1: Post-harvest losses along the F&V supply chain

		Postharvest losses of the crops produced	Proportion of the post-harvest losses at different chain nodes (%)				Causes of PHL
Author	_Fruit or Vegetable	Total PHL along the entire chain	Harvesting stage	Transporting stage	Marketing and distribution stage	Shelf life of Fruits and Vegetables stay without damage (days)	
Msogoya & Kimaro, 2011	Mangoes	43.8	6	24	70		
Mgonja & Utou, 2017	Oranges	7.6				14	
National Post harvest losses strategy 2019-2029	Mangoes	43.8	6.3	24.2	69.8		
Mwagike & Mdoe, 2015	Tomatoes	40-50	2.0		39		
Kulwijila, 2021	Grapes		23			7.2	
Samwel, 2019	Tomatoes					5-8	
Dome & Prusty, 2017	Tomatoes	10-32					
HELVETAS, 2014							Rodents, heavy rainfall during harvesting

Kereth *et al.*, 2013	Fruits and vegetables		More than 3days	Rotting, rodents, poor roofing materials

Postharvest handling practices and technologies of F&V in Tanzania

Number of practices and traditional storage facilities for handling fruits and vegetables in Tanzania exist (Table 2). The manual harvesting through hand picking, shaking trees & stick biting of the produces dominates harvesting approaches (Kereth *et al.*, 2013). The losses are further enlarged by poor transporting mechanisms of heads, carts, bicycles, motorcycles and general-purpose vehicles (Plate 1). The PHL is worsened with poor means of storage of the produce given its perishability nature. Actually, the main storage facilities and practices includes putting fruits and vegetables on heaps of the other under tree shades, the use of bamboo baskets and sisal sacks (Table 2). Indeed, retailing of F&V Tanzania is done at the market place, along the road side (Plate 2) and in the viosk market centers & surrounding the households (Plate 3).

Plate 1. Transportation of fruits and vegetables to market

The storage facilities used in Tanzanian markets don't have components of temperature regulations. The prevalent post-harvest handling technologies and practices for F&V in the country aggravate the PHL along the chain. The severe PHL occurs at retail node where the consignment stays longer than at other nodes of the chains. Therefore, it is important to device mechanism under which the F&V PHL could be minimized. ZECC stands a better chance to lessen the damages due to its low acquisition and operational costs, its relatively huge volumes of F&V handled and its ability to extend shelf life of fresh foods like F&V.

Table 2:

Postharvest handling practices for F&V in Tanzania

Author	**Location**	**Fruits and vegetables**	**Harvesting modes**	**Transporting modes**	**storage**
Mwagike and Mdoe, 2015	Iringa	Tomatoes	Manually	Carts pulled by animals, lorries	Bamboo baskets, open space under the shade

HELVETAS, 2014	Singida	Tomatoes & onions	Manually		
Dome and Prusty, 2017	Arusha	Tomatoes, cabbages, carrots			Open air market
Issa *et al.*, 2021	Daresalaam	Fruits and vegetables			Open space on the floor, bamboo baskets, wooden boxes, plant leaves, canvas sheet
Wakholi *et al.*, 2015	East Africa	Fruits and vegetables	Manually	Carts and/or bicycles	Collection baskets, sisal sacks
Msogoya and Kimaro, 2011	Morogoro	Mangoes		Lorries	Shelter sheds, bamboo baskets
Mgonja and Utou, 2017	Coast region	Oranges	Manually	General purpose vehicle	
HELVETAS, 2014	Singida	Onions, tomatoes		Bicycles, oxcart, morotcycles	Open spaces & sacks
Kereth *et al.*, 2013	Bagamoyo	Fruits and vegetables	Manual	Lorries	Plastic sacks, bamboo baskets & wooden crates

Plate 2. Retailing of F&V along the road sides

Plate 3. Retailing of F&V at market centers

The costs of PHL of F&V in Tanzania

Post-harvest losses of F&V in Tanzania cost the nation up to six trillion Tanzanian shillings per annum (Table 3). It is worth looking at ways to rescue this huge amount of money losses on annual bases. The total value of PHL along F&V

supply chain (six trillion shillings) accounts for more than one sixth (16%) of the annual government budget for 2021-22 that amounted to 36trillion (URT, 2021a). The value of losses would have paid salaries of the whole public servants in 2021-22. Moreover, the lost value would have been shared among chain actors to and increase affordability of the produce to final consumers. Actually, a number of nutritional studies contend that low consumption of F&V is associated with expensiveness of the produce and low affordability among low income earners (Blakstad *et al.,* 2021; Kamugisha *et al.,* 2022)

Table 3

Potential Value of F&V to be recovered by ZECC

S/n	Item	Fruits	Vegetables
1	Average Annual Production (tons)	4,731,795	1,483,809
2	50% of produced Fruits and Vegetables lost at room temperature (tons) [1*0.5]	2,365,898	741,905
3	F&V lost after using ZECC reduces PHL to only 5% of the produce (tons) [1*0.05]	236,590	74,190
4	Quantities F&V that would be lost, but rescued due to use of ZECC at 95% (tons) [2-3]	2,129,308	667,714
5	Average price of F&V (Tsh/ton)	2,169,645	2,149,160
6	Total value of F&V rescued from PHL (Average price of F&V(Tsh/ton) * Quantity rescued from PHL (tons) [4*5]	**4,619,842,238,696**	**1,435,024,488,885**

Source: Computation from Numbeo, 2022; Samwel, 2019; URT, 2016, 2020a, 2020b, 2021b

Conclusion

Tanzanian horticultural industry employs about 4.5 million residents; and it has sustained annual growth rate of 11% in the last decade However, The PHL in the sector amounts to six (6) trillions. The huge PHL are attributed to manual harvesting, poor modes of transportation and poor storage & marketing facilities.

Huge PHL in the F&V industry calls for deliberate efforts to strengthen the marketing environment. It is recommended that ZECC be employed at retailing nodes in the municipal markets where F&V stays longer than at any other node; and experiences the largest amount of PHL. Investment in ZECC technology structures can be piloted in different agro-ecological zones of the country namely Eastern Zone, Northern Zone, Central Zone, Lake Zone and Southern Highland Zone. In the pilots, the Cost Benefit Analysis can be performed to identify feasibility of the project. Upon completion, if investing in ZECC is economically feasible, investors would be informed to invest in the technology whereby retailers can be renting the premise to store F&V at the reasonable price.

Actually, piloting would give answers to economic questions like at which rate the project can be made, when to breakeven, pricing mechanisms for the storage service and other economic aspects of the investment.

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