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Evaluating evaporative cooling system as an energy- free and cost- effective method for postharvest storage of tomatoes (*Solanum lycopersicum* L.) for smallholder farmers

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ABSTRACT

This study evaluated the effectiveness of a low-cost evaporative cooling system and its effect on postharvest storage potential and physicochemical quality properties of tomatoes. The performance of the cooling system was evaluated in terms of temperature drop, increase in relative humidity (RH) and cooling efficiency. Two tomato cultivars ('9065' jam and round) were harvested from smallholder farms in Umsinga, South Africa (28°45′56.45″S, 30°33′42.37″E). Tomatoes were assigned to one of the three storage conditions namely; evaporative cooling system (ECS), cold room (CR) and room temperature (RT). Quality parameters evaluated included mass loss, respiration rate, colour, firmness, total soluble solids and titratable acids for both tomato cultivars. ECS reduced temperature to 19.8 °C which was 13% lower than RT (23.0 °C). RH increased from 63.59% in RT to 83.91% in the ECS with an average cooling efficiency of 67.17%. Storage treatments and time had significant ($p < 0.05$) effect on fruit quality. Fruit in the CR retained colour, mass, firmness, respiration rate, TA and TSS of both cultivars longer than the other treatments. However, the ECS was able to preserve the freshness of tomatoes for 20 days and had a slower rate of change in mass, respiration, colour, firmness, TA and TSS compared with those stored at RT. This suggested that the evaluated ECS is capable of maintaining postharvest quality and increasing shelf-life of tomatoes. Therefore, ECS has a potential as a low-cost and energy-free system for preserving quality and reducing postharvest losses under smallholder farming systems.

1. Introduction

Tomato (*Solanum lycopersicum* L.) is considered one of the most widely cultivated horticultural crops in the world (Ajayi and Oderinde, 2013). In human diet, tomatoes are famous for providing beneficial minerals, vitamins and phytochemicals such as carotenoids, lycopene, and flavonoids. These phytochemical compunds assist human body to fight various non-communicable diseases such as cardiovascular and some cancer diseases (Nino-Medina et al., 2013). The aforementioned reasons have contributed significantly to the demand for tomatoes in most fresh produce markets, including developed and developing countries (Falah et al., 2015). Although tomato is an important vegetable crop, it is inherently perishable, leading to postharvest losses before the produce is consumed (Vinha et al., 2013). Nasrin et al. (2008) argued that, due to lack of information on appropriate storage conditions, horticultural products lose their quality and encounter several problems during storage and transportation until they reach markets, where they probably are disposed.

Cooling is the most traditional way of preserving horticultural products and the most common way of keeping quality whilst increasing the shelf life of any harvested produce (Munoz et al., 2017). However, for smallholder farmers mostly in developing countries, appropriate storage facilities for fruit and vegetables are not taken into consideration in their planning, mostly due to lack of knowledge and resources (Kasso and Bekele, 2015). This leads to postharvest losses which is one of the reasons hindering the success of smallholder farmers. Postharvest handling of fresh produce by these farmers is poor mainly because they do not have access and/or cannot afford proper postharvest technologies and adequate postharvest management practices for these perishable products in the value chains (Lebotsa, 2004;

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Prusky, 2011). Furthermore, these resource-poor smallholder farmers either have no access to electricity or cannot afford the current high costs of electricity. Moreover, smallholder farmers may not be familiar with cheaper and energy efficient alternatives for postharvest technologies (Thamaga-Chitja and Hendriks, 2008).

Olusunde et al. (2016) estimated that postharvest losses due to improper storages in these countries are as high as 30–40%. Mogaji and Fapetu (2011) strengthened findings of Olusunde et al. (2016) estimating 20–50% losses due to improper storages in developing countries. This is a drawback to smallholder farmers as it causes farmers to lose value for their products due to their perishable nature. During production season, farmers have to harvest and sell or consume within a short period to avoid waste due to improper handling. According to Munoz et al. (2017), since most smallholder farmers have no particular means of sorting, produce get affected by poor handling procedures reducing postharvest quality, shelf life and return on investment. Although the postharvest problems are known to reduce profits, smallholder farmers cannot refrain from producing fruits and vegetables since these crops contribute significantly to alleviate food and nutritional insecurity.

For smallholder farmers to become sustainable, there is a need to develop and introduce postharvest management programs with the objective to reduce postharvest losses of perishable horticultural products. Research has indicated that smallholder farmers and informal traders in rural areas continue using cultural storage methods that do not preserve fresh produce quality and do not extend postharvest shelf life (Lal Basediya et al., 2013). Some of the cultural storage methods used by the farmers include storing the produce in cool dry rooms dependent on natural ventilation, wooden huts, household refrigerators or placing produce on the floor and covering it with plant leaves (Lal Basediya et al., 2013; Liberty et al., 2013). These methods are ineffective compared to the commercial postharvest cooling systems, such as refrigerated cold rooms and the controlled atmosphere storage.

Similar to any postharvest management system, smallholder farmers need to consider temperature and relative humidity when handling perishable fresh produce such as tomatoes. Temperature and relative humidity are important environmental factors known to play a vital role in the postharvest quality of fruits and vegetables (Chinenye, 2011; Vala et al., 2014). These two environmental factors have been reported to affect processes such as respiration, moisture loss, and growth of postharvest pathogens on harvested products (Jobling, 2000). There is, therefore, a need for these parameters to be monitored and maintained within threshold values for any selected produce. This can be achieved through the use of proper storage facilities such as mechanical refrigeration, hydro-cooling and vacuum cooling. However, these storage facilities are expensive and are not affordable to smallholder farmers with limited resources.

If the problem of poor postharvest handling by smallholder farmers is not tackled, postharvest losses will continue to be the bottleneck that discourages smallholder farmers from participating in the mainstream agricultural economy. Therefore, there is a need for the proper adoption of cost-effective and energy efficient postharvest management system tailor-made for preserving quality, extending shelf life and reducing postharvest losses of perishable horticultural produce in smallholder farming. Among several postharvest management systems, evaporative cooling system (ECS) is known to be an economical and efficient technology for reducing temperature, increasing relative humidity and also increasing the shelf life of horticultural produce (Lal Basediya et al., 2013). Evaporative cooling system is structured differently from the known refrigerators or air conditioning technologies (Birch et al., 2015).

Evaporative cooling system can provide cooling without the need for electrical power source, reduce storage temperature, increase relative humidity, maintain the quality of produce, protect food safety, reduce produce losses between harvest and consumption and help keep the freshness and prolong shelf life of horticultural commodities (Chinenye, 2011). Workneh and Woldetsadik (2004) stated that the cooling system works by passing air through a wet pad. Water from the wet pad evaporates and thus removes heat from the air while adding water and providing cooling to the storage chamber (Mogaji and Fapetu, 2011). Unlike hydro-cooling, mechanical refrigeration and vacuum cooling, evaporative cooling systems are cheaper, efficiently use electricity, do not use refrigerants, are environmentally friendly and do not require high initial investments. However, the cooling efficiency and postharvest performance of tomatoes stored in evaporative cooling system has not been evaluated.

Therefore, this study was conducted to develop and evaluate the performance and efficiency of the low cost evaporative cooling system on temperature relative humidity and maintaining physico-chemical properties of tomatoes.

2. Materials and method

2.1. Experimental site

The study was conducted during 2016/17 season at Nhlesi in Umsinga (28°45′56.45″S, 30°33′42.37″E) located in the UMzinyathi District in KwaZulu-Natal province, South Africa.

2.2. Description of the evaporative cooler and its cooling system

The evaporative cooler was made up of 80 mm thick prefabricated walls of which 20 mm was the white-painted plain carbon steel (mild steel) laminated on the inner and outer wall sides of the 60 mm thick polystyrene insulating foam. The dimensions of the constructed evaporative cooler were: length (L) = 3.85 m, breadth (B) = 2.85 m and height (H) = 2.35 m hence, the volume was 25.8 m^3. As shown in Fig. 1, the evaporative cooling system consists of a cooling pad, suction fan, a Go Power (GP) solar plate, two small computer fans, water tank and hose pipes as water distribution components. The room was located at the center of the smallholder farmer's field for easy access to all the farmers. The structure of the evaporative cooler was chosen because of its advantages such as fireproof, all-weather material, wind resistant, environmentally friendly and energy conserving (Swierk, 2005). Moreover, the white colour of the evaporative cooling system allows the evaporative cooler to reflect light, therefore, minimum heat can be absorbed (Barnard, 2011).

The material used and the actual cost of constructing the evaporative cooling system are provided in Table 1. The structure is considered low cost because unlike the famous cooling methods (refrigeration system, hydro cooling, vacuum cooling) the system does not use refrigerants, electricity, lots of water, electric motor, refrigeration units, water discharge chamber (Vigneault et al., 2000). Furthermore, the system will be reviewed again after at least 5/8 years which makes it cost effective and an efficient cooling method for smallholder farmers. Evaporative cooling systems are an economic and energy efficient method used to reduce temperature and increase relative humidity with minimum or no electricity. Therefore, in comparison with other cooling methods such as the refrigeration unit, the system is efficient as it uses solar energy which is cost effective for the farmers.

The prefabricated room was placed on a concrete slab. To extract warm air from the evaporative cool room, a fan was located 1.5 m high on the opposite wall to the cooling pad of the cooling system. A 150 L water tank was placed on top of concrete blocks in order for the water movement from the tank to the cooling pad to be able to flow and reach the cooling pad efficiently. Water flow from water tank to cooling pad was possible through the use of hosepipe. The hosepipe was connected from the water tank to cooling pad. The cooling pad was properly fitted in a metal frame structure to prevent it from weakening fast. After the frame was created around the cooling pad, the area of the visible brown cellulose paper part of the cooling pad is 0.45 m^2 (L = 0.97 m, B = 0.46). On the inside side of the ECS in front of the cooling pad, 2