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Design and Technical Evaluation of Evaporative Cooling for Prolonging Fresh Potato Shelf Life in Tropical Climates

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Abstract: Postharvest damage to potatoes can occur due to plant physiological disorders, such as evaporation (transpiration), respiration (respiration), tubers sprouting, and tubers becoming too ripe. This research aims to design, manufacture, and test an evaporative cooling device using a direct spray method from a fan into a room or box by conducting technical tests about temperature, humidity (RH), signs of potato damage, weight loss, and water content. The test was carried out using an evaporative cooling device (evaporative cooler) for 30 days. This research tested the effectiveness of the evaporative cooling system compared to room outside storage on potato quality for 30 days observationally. The results show that evaporative cooling equipment can prolong the shelf life of fresh potatoes in tropical areas according to physical parameters such as signs of damage to potatoes during storage, water content, and percentage of weight loss. For future development, increasing the fan and cooling pad to medium size is necessary for more effective equipment. An evaporative cooler is a cost-efficient and sustainable method for preserving agricultural produce in rural areas far from urban centers.

Keywords: Agricultural engineering; Coco coir pad; Environment; Evaporative cooling; Shelflife.

Introduction

Potatoes are one of the vegetables that require good postharvest handling. Postharvest damage to potatoes can occur due to plant physiological disorders, such as evaporation (transpiration), respiration (respiration), tubers sprouting, and tubers becoming too ripe (Zhang et al., 2024; Alexopoulos & Petropoulos, 2021). As a result, potato tubers often lose yield due to both the weight of the material and the quality of the tubers in terms of changes in nutritional content (Muhie, 2022). Postharvest of potatoes is an activity that starts with the material after being harvested until it is ready to be marketed or used by consumers when it is still fresh or ready for further processing in the industry (Yakimenko & Naumova, 2018). To reduce postharvest damage, proper and optimal storage techniques are needed. Several storage methods for quality tubers need to use the principle of reducing as little as possible the occurrence of respiration and transpiration (Jakubowski & Królczyk, 2020). Cooling is the use of low temperatures (below low temperatures) and is generally aimed at maintaining the freshness of ingredients. The problem arising from low-temperature storage of potatoes is that they turn sweet, which is unsuitable for processed potatoes because they will turn brown. Potatoes are one of the most widely grown food crops throughout Indonesia. Potato cultivation is relatively easy and can be planted in all parts of Indonesia. As part of the Poaceae family, potatoes are full of carbohydrates

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(17.49 g/100g) and starch (15.29 g/100g), where water is the main food ingredient in Indonesia. Potato is one of the horticultural commodities from the tuber vegetable group, and it has excellent potential as a source of carbohydrates. Potatoes have good potential and prospects to support diversification programs to achieve sustainable food security (Singh et al., 2020). The quality of potatoes is determined mainly by postharvest treatment carried out by farmers and sellers. Potato, as a carbohydrate-rich food, is generally associated with a high glycemic index and glycemic load, which means eating potatoes has promisingly positive effects on our overall health (Xu et al., 2023).

Postharvest treatment of potatoes generally includes collection, washing, sorting and classifying, storage, packaging, and distribution. Farmers in Indonesia generally store potatoes in storage warehouses. The condition of the storage warehouse is an essential factor that needs to be considered when the tubers are experiencing a period of dormancy (Kasampalis et al., 2021). Potatoes are a type of tuber with scaly shoots that can become new plants (Rahman et al., 2024). Improper storage methods and times can stimulate shoot growth. Light plays a vital role in physiological processes. Storing in an open container (exposed to light) will affect breaking dormancy in potato tubers by increasing the temperature and storage time. The unpredictability of the potato tuber formation period can lead to early sprouting prior to harvesting. So, aligning the tuber formation with the harvesting period is crucial to avoid this issue. Therefore, preserving potato quality and storability after harvest has become a critical concern for economic stability and global food security. Morphological analysis of changes in the morphology of potato tubers is an effort to determine the level of suitability for consumption as a functional food ingredient (Zhang et al., 2024; Di et al., 2024; Asgar, 2011).

After harvesting, fruits and vegetables undergo respiration, transpiration, and ripening. Optimum storage conditions, such as temperature and relative humidity, can minimize decay processes (Brasil & Siddiqui, 2018). Cooling uses electricity and is a process where the temperature of storage is lowered to maintain good storage, but it needs more energy. Evaporative cooling can be a sustainable and cost-effective method for extending the shelf life of potatoes, especially in regions with suitable climates (et al., 2015). Evaporative cooling is an air conditioning system that uses water to cool and add water content or humidity to the airflow (Kapilan et al., 2023). So, the dry bulb temperature becomes cooler than before undergoing the evaporation process. There are two types of evaporative cooling processes, namely, the direct evaporative cooling process and the indirect evaporative cooling process. In the direct evaporative cooling process, environmental air is drawn in by a fan passing through a wet medium (cooling pad or water jet). In the wet media, a jet of water is sprayed through a sprayer, resulting in contact between air and water and becoming mist. So evaporation and cooling occur. Meanwhile, the indirect evaporative cooling process is a continuation of the direct evaporative cooling process; the output from the direct evaporative cooling process is passed through a heat exchanger. The heat exchanger is where heat transfer occurs between the hot environmental air flowing and the cold air produced by direct evaporative cooling. One way of cooling that can be done is with the evaporative cooling technique. This evaporative cooling can be done (Nusa, 2015).

The primary function of evaporative cooling is to reduce the temperature and increase the relative humidity of the surrounding air before it enters the storage space by passing it through a wet medium, which functions as a cooling medium (cooling pad), specifically in direct evaporative cooling systems. It has been reported that preserving fruit and vegetable storage conditions with low temperature and high relative humidity will reduce pathological activity and thus prolong storage time. Reducing temperature and increasing air humidity in the storage room will suppress enzyme activity and respiration of fruit and vegetables, thereby in hibiting loss of water content and reducing the rate of formation of ethylene gas and metabolic activity (Nusa, 2015). Evaporative cooling is used to lower the temperature and increase the humidity in the storage environment of fruits and vegetables. This method relies on natural evaporation to achieve these goals, which is particularly effective in hot and dry climates. The main functions of evaporative cooling include temperature reduction. Evaporative cooling reduces the temperature by converting water into vapor, which absorbs heat from the air. This cooler air is then circulated to the stored fruits and vegetables, helping to slow down their respiration rates and metabolic processes, thereby prolonging their shelf life (Salim & Farooq, 2020). Evaporative cooling prevents the dehydration of fruits and vegetables. High humidity levels are crucial for maintaining the freshness and weight of the produce, preventing it from drying out and losing quality (Tejero-González & Franco-Salas, 2021). Lowering the temperature and increasing the humidity helps maintain the produce's visual and nutritional quality. It reduces the risk of spoilage and decay, often accelerated by high temperatures and low humidity. Evaporative cooling uses less electricity, making it a cost-effective and environmentally friendly option for preserving produce. The direct evaporative cooling technique using the spray method was carried out, and the air temperature in the room was reduced

(Yenenh, 2023). Because it can lower the room temperature to make it cooler, evaporative cooling is often used not only to extend shelf life, but also to cool the room. (Antaryama, 2022; Yunianto, 2018).

However, there has been no technical study of the application of coco coir pad-based evaporative cooling for potato storage in Indonesia. Therefore, this evaporative cooling system was designed, constructed, and tested. It also analyzed how it performs, increasing effectiveness in prolonging the shelf life of potatoes, and what effect it has on the quality and physical characteristics of stored potatoes. It is hoped that from this research, a workable and cheap way to maintain the shelf life of potatoes will be obtained using the "evaporative cooling" equipment so that it can help farmers store potatoes.

Method

This research was carried out in three months in the Agricultural and Biosystems Engineering Laboratory, Faculty of Agriculture, Department of Agricultural Technology, Sam Ratulangi University, Manado.

Materials and Equipment

The materials used in this research were harvest-aged potatoes, ranging from 4 months to 20 kg potatoes, taken from garden produce in the Modoinding area, South Minahasa Regency, Indonesia. The equipment used in this research is 1) Evaporative Cooling equipment for storing potatoes. 2) Analog scale with a capacity of 100 kg to calculate the weight of potatoes; 3) HTC-2 to measure temperature and humidity (RH) in the Evaporative Cooling device and the outside room as a control. 4) Oven, for measuring the moisture content of materials; 5) Anemometer, for measuring wind speed; 6) Writing tool, to record each observation result obtained in the research; 7) Sack, for storing potatoes; 8) Mobile phone as a documentation tool and stopwatch, 9) Laptop, for data processing and analysis, 10) Cooling fan, to push air into the equipment, 11) Timer for time calculation.

This research uses an observational method to observe the changes in fresh potatoes stored in the equipment. Data analysis is done by collecting data, processing it, then presenting it in tables and graphs, and finally describing it. The observation was carried out using an evaporative cooling device with two experiments carried out over 30 days, and the material used was 20 kg of potatoes each.

Evaporative Cooling Functional Design

The evaporation cooling device design comprises the main components: shelves and cabinets, a cooling fan, and a cooling pad transmission. Shelves and cabinets provide organized storage space for potatoes and ensure proper air circulation around the stored potatoes, promoting uniform cooling. A cooling fan moves air through the cooling system. It circulates the cooled air throughout the storage area, ensuring even temperature distribution. A cooling pad acts as the medium through which air is cooled. The transmission system distributes water over the cooling pads. The cooling pad has coconut fiber inside to absorb the water, and a tank of water is up to ensure that the cooling pads remain wet for continuous evaporation. A control system uses an on-off system to control water flow from the tank through the pad to wet the cooling pad. The design of the evaporative cooling tool (figure 1) is a system consisting of a shelf rack and cooling chamber (cabinet), cooling fan, and cooling medium transmission (cooling pad). The control system controls incoming cold air using a timer through the cooling pad, monitoring the temperature inside and setting the evaporation. The research was conducted experimentally by measuring the distribution of temperature and RH in the cooling room with cooling treatment using a fan that blows air through the coir pad into the cooling room. The effectiveness of coconut coir in evaporative cooling can be understood when water is exposed to air and evaporates; it absorbs heat from its surroundings, lowering the temperature.

Coconut coir was used as a cooling medium and has been proven to reduce temperature and increase humidity. Coir has a highwater retention capacity due to its fibrous nature and holds a large amount of moisture, which is gradually exposed to the passing air. The fibrous structure of coconut coir provides a large surface area for evaporation. As air passes through the moist coir, the water stored in the coir evaporates into the air. Water evaporates from the coir and absorbs heat from the surrounding air. This process results in a cooling effect on the air. On the other hand, as water evaporates from the coir and enters the air, the humidity level of the air increases.

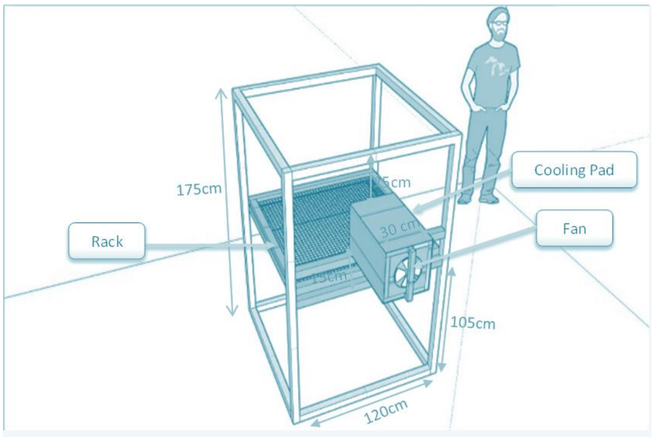

Figure 1. Design of Evaporative Cooler

Figure 2. Evaporative Cooler

Research Procedure

Sample preparation begins by selecting potatoes of uniform quality from the same population, ensuring optimal conditions without defects that could affect the research results, and analyzing initial parameters such as weight, size, water content, and pH. After that, the potatoes were divided into two groups: those stored without evaporative cooling (outside the equipment) and those that used evaporative cooling (inside) as in figure 2. Both groups were kept under uniform conditions, maintaining consistent room temperature and humidity. Daily data such as temperature, humidity, and visual condition of the potatoes are recorded to monitor physical changes. Humidity and temperature measurements are carried out periodically to understand the effect of Evaporative Cooling on overall storage conditions.

Observation Variables

Observed variables are temperature, RH, Signs of potato damage, Water content, and Weight loss.

Measurement of temperature and humidity (RH)

The temperature in the evaporative cooling equipment, the temperature of the space, and relative humidity in the evaporative cooling equipment and the space were measured using the Digital Thermo Hygrometer (HTC-2)

Water Content measurement

Water content measurements are done using drying methods in the oven. Potatoes weigh 5-6 grams and are placed in an aluminum foil cup known to be empty. The sample is dried in a 105°C oven. Drying took 4-5 hours. It was then cooled in a sub-desiccator 15 minutes ago and weighed again. This behavior is repeated until it is recorded heavily. After gaining initial and final weight, the water rate can be calculated using the equation formula (1).

$$m=\frac{Wm}{Wm+Wd}x100\% \quad (1)$$

Description:
m = wet base water content (%)
Wm = Heavy water in substance (gr)
Wd = Absolute dry matter weight (gr)

Weight loss

Boat corners are obtained by weighing potatoes at the beginning and after entering storage to determine how heavy the potatoes are at the beginning and after storage. The boot angle can be calculated using the Formula 2.

$$W=\frac{A}{B}x100\% \quad (2)$$

Description:
W: Weight change (g)
A: Initial sample weight (g)
B: Weight of sample day n (g)

Characteristics of potato damage

Measuring potato damage was observed potatoes in the evaporative cooling device and the outside room daily for 30 days. Calculate the percentage of signs of potato damage, know the damaged potatoes (kg), and calculate the percentage of the total potato weight. Signs of potato damage can be calculated using formula 3.

$$V=E/Z \text{ x } 100\% \quad (3)$$

Description:
V: Percentage of potato damage
E: Weight of damaged potatoes
Z: Weight of whole potato

Result and Discussion

Temperature

The average storage temperature data in Evaporative Cooling and space over 30 days show an exciting pattern of change. The average temperature in the evaporative cooling device varies from 25.3°C in the morning until it reaches its peak at 11:00 at 29.2°C, then falls at night. Meanwhile, room temperature also fluctuates, reaching the highest point at noon at 31.5 °C. The temperature changes follow daily patterns, rising in the morning and falling at night. The temperature chart during storage is in Figure 3.

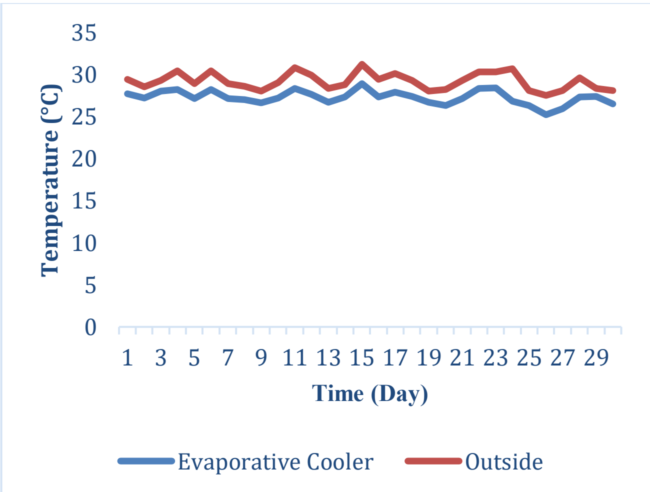

Figure 3. Average temperature during storage 30 days

The average temperature of Evaporative coolant use (26.9°C) shows a significant decrease compared to the average room temperature (29.8°C), describing the effectiveness of an Evaporative coolant system in lowering air temperature by boiling water (figure 3). However, both temperature categories show significant fluctuations from day to day, which various factors, including weather change, sunlight intensity, and season, can influence. However, evaporative coolants significantly lower room temperature when external air temperature rises and maintaine temperature. Lower temperatures and higher humidity in evaporative cooling conditions have a positive impact on slowing down the potato rotting process, along with the number of rotten potatoes being lower compared to conditions without evaporative cooling. Lower temperatures in evaporative cooling conditions can slow the potato rotting process. Thus, setting a stable and low can be a critical factor in maintaining potato quality during the storage period. According to Nusa (2015), Reducing temperature and increasing air humidity in the storage room will suppress enzyme activity and respiration of fruit and vegetables, thereby in hibiting loss of water content and reducing the rate of formation of ethylene gas and metabolic activity.

Relative Humidity (RH)

Moisture during potato storage conditions using Evaporative Cooling offers higher and more stable moisture, ranging from 52 to 63, which creates a flexible and conducive environment (figure 4). Although there is a slight fluctuation, the overall humidity remains stable in the optical range.

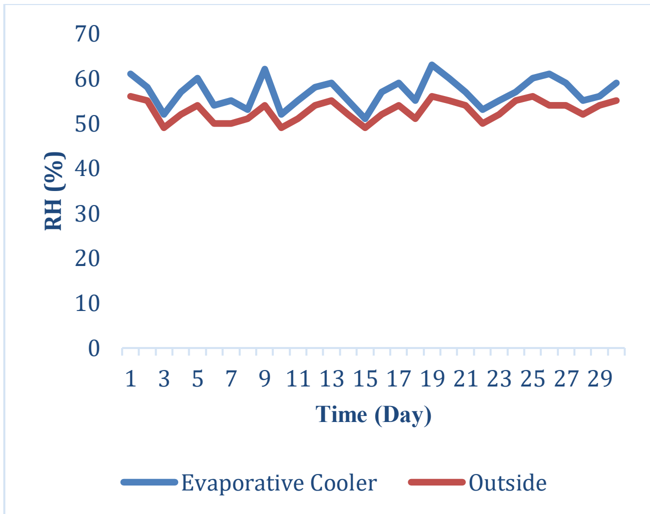

Figure 4. Average humidity during 30 days of storage

Three signs of potato damage during storage the results of data collection during storage show differences in damage to potatoes using Evaporative Cooling equipment and those not using the Evaporative Cooling equipment. Table 1 is a table of signs of potato damage during storage. The use of evaporative cooling in potato storage has a positive effect on slowing down fertilization, especially seen from lower soft potatoes than without evaporative cooling. A significant difference in the amountof soft potatoes between the two storage conditions confirms the effectiveness of Evaporative Cooling in maintaining potato quality. However, no significant impact on tuna growth appears on potatoes between these two conditions. Although the number of rotten potatoes tends to be lower in storage with evaporative cooling, this difference is not so ridiculous because the amountof rotten potatoes is relatively tiny in both storage conditions. However, evaporative cooling tends to slow down the incineration of potatoes, showing its potential as an effective method of prolonging potato storage life by reducing damage during storage—Table 2.

Water content

The water content in potatoes indicates the level of warmth, so it significantly impacts the mute, especially the physical mute. Based on the results of the statistical tests, there is an interaction effect between initial and final water content that can be seen in Tables 3 and 4. Analysis of water content in the three groups shows exciting patterns. It showed a change of 6.82%, indicating a significant decrease in water. Meanwhile, the middle group noted a more significant change, reaching 9.36%, indicating a more substantial influence or behavior on water rate changes. However, what was recorded was the most significant change, 14.25 percent. The result suggests that without any special treatment, the grouping experienced the most significant changes in water content among the three groups.

Weight loss

The results of measuring potato sequences using the evaporative cooler for 0-30 days at an average temperature of 26°c range between 6%. While the potato sequence stored in the room for 0-30 days at an average temperature of 29°c ranges from 12%. Storage temperature control and conditioning for changes are in Table 5. In storage with evaporative cooling, there is a consistent weight decrease between 0.2 kg and 0.5 kg over 30 days. It should be noted that the temperature of approximately 26°C in this group results in lower boiling fluctuations than in storage in a room at 29°C. On the other hand, storage in the room also suffered a heavy drop for 30 days, although at a slightly higher level than storage evaporative cooling, especially at a higher temperature, namely 29°C. Evaporative cooling storage at an average temperature of 26°C tends to produce lower boiling changes than storage in a room at an average temperature of 29°C.

Conclusion

Using evaporative cooling equipment to store potatoes results in more controlled and relatively stable temperature changes than outside room storage. Evaporative cooling in potato storage produces a more optimal environment with higher and more stable humidity, ranging from 52 to 63. Evaporative cooling creates moist and conducive conditions for potatoes, which can help maintain the texture and freshness of potatoes during storage. Evaporative cooling in potato storage has a positive effect on slowing potato rot by showing a lower number of mushy potatoes compared to storage without evaporative cooling. Storage in evaporative cooling has a positive impact on slowing down the overall potato rotting process. Storage with evaporative cooling tends to retain potato moisture content better, resulting in lower weight changes than outside storage. Storage with Evaporative Cooling at an average temperature of 24°C shows a potato weight loss of 6%, while storage in a room at an average temperature of 29°C shows a weight loss of 12%. This indicates that storage temperature plays a vital role in influencing the stability and quality of potatoes.

Further research must be carried out using evaporative coolers, especially to be more efficient and effective. Cooling pads are essential because they provide a large surface area for water to evaporate as air passes through the wet pads, cooling down as the water evaporates. Although necessitating increased energy input, implementing more giant fans and expanded cooling pads is imperative. Evaporative coolers represent a viable, cost-efficient, and sustainable method for is an affordable storage technology for rural areas. Their minimal energy consumption, maintenance requirements, compatibility with arid climates, and environmentally conscious characteristics render them an auspicious option for rural development projects to fortify food security and elevate the quality of life within rural communities. Evaporative cooling technology can be integrated into science-based agricultural engineering curricula, particularly in courses related to post-harvest technology and agricultural building engineering. This integration can strengthen understanding of appropriate technological solutions that can be applied to farmers.

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Author Contributions
I.A.L.: Developing ideas, analyzing, writing, reviewing, responding to reviewers' comments; D.T., J.Y.M.: analyzing data, overseeing data collection, reviewing scripts, and writing; LC.C.E.L, H,F.P., D,S.: participated in data interpretation and writing.

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Conflicts of Interest
The authors declare no conflict of interest.

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