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Original Research Article

Performance Evaluation of Truck Equipped with the Evaporative Cooling System during Transportation of Vegetable

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Abstract: The research describes the development of an evaporative cooling system in a non-refrigerated truck for the short-term storage of vegetables during transportation. The system comprises an evaporative cooler, storage unit, power supply, control panel, and real-time data monitoring for temperature and relative humidity. Computational fluid dynamic (CFD) simulation was conducted to investigate the temperature and airflow distributions in the evaporative-cooled storage unit for five different configurations of air inlet and outlet. The configuration of one air inlet (front — lower left) and two air outlets (top — front and back centre) of the storage unit was shown to provide optimum temperature and airflow distributions and hence, was applied in the system modification. The functionality and performance of the modified system were then evaluated in terms of the cooling profile of the storage units and leafy vegetable quality for the fresh market. Three storage treatments for the selected vegetable were investigated, i.e., evaporative-cooled truck (T1), canvas truck (T2), and cold truck (T3) during a five-hour journey from Cameron Highlands to Serdang. The average temperature inside the storage units was T3 < T1 < T2. Evaporative-cooled truck exhibited an average temperature reduction (ΔT) of 10°C from the ambient condition. It also demonstrated a relative humidity of >90%, which was in agreement with the recommended relative humidity for leafy vegetable storage. Post-five-hour storage treatments, vegetable stored under T1 exhibited the least weight loss as compared to T2 and T3. The results indicated that the evaporative cooling system manages to preserve vegetable quality soon after harvesting, hence the potential to reduce postharvest loss during transportation.

Keywords: evaporative cooling; short-term storage; transportation; cooling profile; vegetable quality

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1. Introduction

Storage of fresh horticultural produce such as vegetables is critical in a tropical climate such as in Malaysia. Vegetables have a very short shelf-life due to their high moisture content and are prone to spoilage if not properly handled and stored. The metabolism in fresh horticultural produces continues even after harvest hence the deterioration rate rose due to ripening, senescence, and weather conditions. The post-harvest losses in fresh produce were estimated to be 40% in Southeast Asia due to a lack of post-harvest management (Gunasekera *et al.*, 2017). In addition, losses at the post-harvest processing and storage stage in Southeast Asia were roughly 9% (Gustavsson *et al.*, 2011). Undoubtedly, storage plays an important role in the food supply chain, and several studies have shown that during this operation, maximum losses will occur (Aulakh *et al.*, 2013; Calverley, 1996; Majumder *et al.*, 2016). Therefore, prolonged freshness and shelf life, and quality maintenance of the horticultural produce are considered the predominant goals in the whole value chain of horticultural production, especially storage.

Many studies have reported on the storage of fruits and vegetables using an evaporative cooling system to preserve the quality of horticultural produce right after harvest such as tomato (Burbade *et al.*, 2017), pumpkin and amaranthus leaf (Chinenye *et al.*, 2013). Yet, the application of the technology for short-term storage management of horticultural produce during transportation is lacking which provides prospects for this research. Inland transportation for horticultural produce in Malaysia is generally via canvas or cold trucks. The use of canvas truck provides a cheaper option, however, at the risk of compromising produce quality. Meanwhile, the cold truck option provides lower produce quality degradation, however, it is relatively more expensive (in terms of installation, energy consumption, and maintenance) (Deoraj *et al.*, 2015). Thus, an evaporative-cooled truck is a renewed interest as an alternative to canvas and cold trucks.

Evaporative cooling is achieved from the evaporation of cooling media, usually water, to the surrounding air to cool the object in contact. The cooling obtained by this system often contributes to high relative humidity compared to the ambient air in the cooling chamber from which the evaporation occurs. Consequently, the atmosphere in the chamber becomes more accommodating for the storage of fruit and vegetables. In principle, increasing the relative humidity in the storage chambers would reduce the rate of water loss and its metabolic activity which in turn prolongs the shelf life of the produce (Liberty *et al.*, 2013). However, high humidity will also result in condensation of water on top of the produces and increase the possibility of rotting. Therefore, it is important to hold the produces within their lowest safety temperature during evaporative cooling, which is usually 10 to 12°C for vegetables (Zakari *et al.*, 2016).

The research aimed to develop a truck equipped with an evaporative cooling system for short-term storage of vegetables during transportation. The temperature and airflow distributions in the evaporative-cooled storage unit were investigated via computational fluid dynamic (CFD) simulation in which then applied in the modification of our previously published system (Sairi *et al.*, 2020). The functionality and performance of the modified system were evaluated in terms of the cooling profile of the storage unit and leafy vegetable quality for the fresh market.

2. Materials and Methods

2.1. Evaporative Cooling System in Non-Refrigerated Truck Development

The evaporative cooling system in a non-refrigerated truck comprises of an evaporative cooler, storage unit, power supply, control panel, and real-time data monitoring (temperature and relative humidity) as published previously (Sairi *et al.*, 2020) is as depicted in Figure 1.

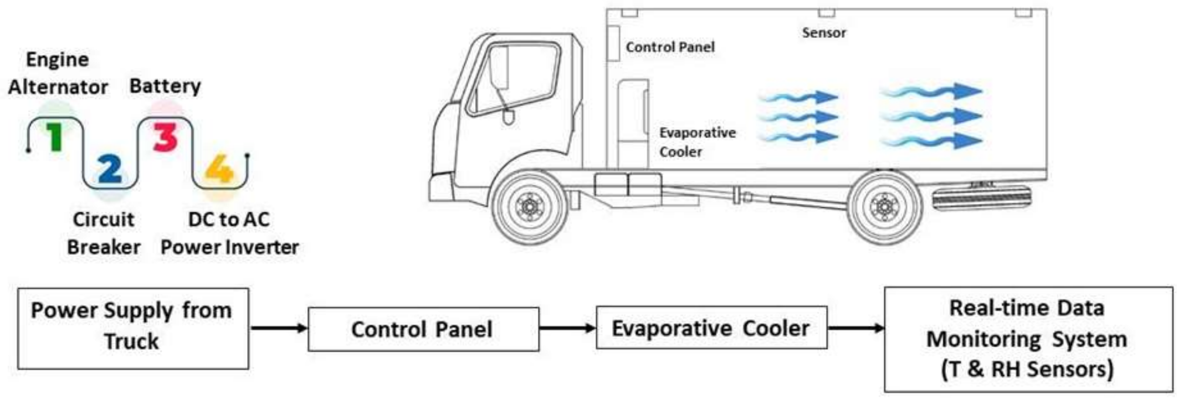


Figure 1. Diagram of the truck equipped with evaporative cooling system (Adapted from Sairi *et al.*, 2020)

2.2. CFD Simulation and System Modification

A CFD simulation study was performed using ANSYS Fluent V14 software (ANSYS Inc., United States) for the determination of temperature and airflow distributions in the evaporative-cooled storage unit. The objective was to find the optimum distribution and balance between both parameters. It analysed the effect of different inlet and outlet configurations on the internal condition of the evaporative-cooled storage unit.

The simulation study results were then implemented in the modification of the system with the installation of intake and outtake air components. The quantity and location of the intake and outtake air components were determined for the optimal temperature reduction in the storage unit.

2.3. Modified System Functionality and Performance Study

The capability of the truck battery (direct current, DC) to power the modified systems comprised of an evaporative cooling and data monitoring systems (alternating current, AC) via a power inverter was evaluated. The system used two units of 12 V batteries in series to produce an input DC 24 V. The output from the power inverter was AC 200–240 V.

On the other hand, the performance evaluation of the modified system during transportation in terms of the cooling profile of the storage unit and selected leafy vegetable quality for the fresh market was conducted. The journey taken was from Cameron Highlands to Serdang which took approximately five hours. The three (3) treatments were:

T1 - Evaporative-cooled truck

T2 - Canvas truck

T3 - Cold truck (10°C)

In this research, the evaporative-cooled truck (T1) applied icy water as an evaporation media and a fixed fan with a speed at 5.1 m/s. Two units of sensors were located inside the storage unit of each treatment and one unit of a sensor for outside (environment) to monitor temperature and relative humidity for the duration of the experiment. The two inside sensors were located inside the front and back of the vegetable baskets, respectively. On the other hand, the outside sensor was attached to the body of the truck equipped with an evaporative cooling system. The differences in temperature and relative humidity between environment (out) and storage unit (in) were recorded.

The saturation/cooling efficiency of a system is defined as in Equation 1 (Khobragade & Kongre, 2016):

$$\varepsilon = \frac{T_1 - T_2}{T_1 - T_{wb}} \times 100\% \qquad (1)$$

where T_1 and T_2 are evaporative dry bulb temperature for outdoor, and indoor, respectively. On the other hand, T_{wb} is evaporative wet bulb temperature for indoor.

2.4. Postharvest Quality Analysis

In this study, choy sum (*Brassica rapa var. parachinensis*), a type of leafy vegetable was directly purchased from a supplier in Cameron Highlands and harvested prior to the experiment (35–40 days after sowing) by cutting the root with a sharp knife. The leafy vegetable was placed into a basket (10 kg each) and randomised into three treatments, i.e., evaporative-cooled truck (T1), canvas truck (T2), and cold truck (T3). The leafy vegetable was then transported from Cameron Highlands to MARDI Serdang which took approximately five hours. The quality of the leafy vegetable for the fresh market that underwent treatments T1, T2, and T3 was assessed. Weight and physical appearance were documented as pre- and post-treatments. Leafy vegetable weight loss was calculated based on a % fresh weight basis. Post-treatment, the leafy vegetable samples were transferred to a cold room set at 5°C at 90% relative humidity, and the subsequent postharvest storage study was conducted for 15 days. The temperature and relative humidity were monitored throughout the study using HOBO® U12 data loggers (Onset Computer Corporation, USA). The postharvest quality of the leafy vegetable was evaluated on days 0, 5, 8, 11, and 15.

The visual appearance of the leafy vegetable was scored subjectively for freshness, leaf colour, leaf wilting, stem wilting and overall acceptability according to the previously published rating for leafy vegetable (Sairi *et al.*, 2020). Soluble solids concentration (SSC) of leafy vegetable was determined by placing a drop of juice on a digital refractometer (Atago DBX-55, Atago Co. Ltd., Japan). Results were recorded in % SSC. pH and total titratable acidity (TTA) were measured using an automatic titrator (905 Titrando, Metrohm AG, USA). TTA of the vegetable juice (3 mL) was titrated with a 0.1 N NaOH solution to the endpoint of pH 8.1 and recorded as % TTA. Ascorbic acid (AA) content was measured using 10 g of blended sample extracted with 100 mL of 3% metaphosphoric acid, filtered through Whatman No. 4 filter paper. Ten mL from the filtered solution was determined by titrating with 2,6-dichlorophenol-indophenol to a pink endpoint that persisted for 15 s. The results were recorded as mg of ascorbic acid per 100 g fresh weight (FW).

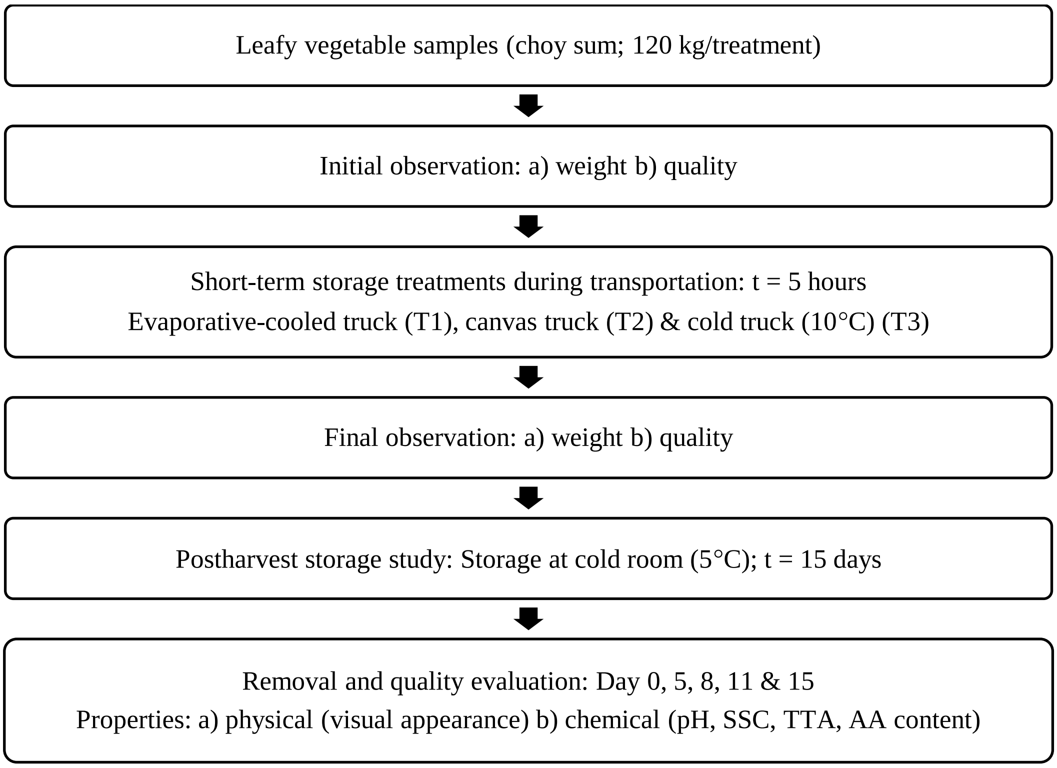


Figure 2. Postharvest Quality Analysis Process Flow

2.5. Statistical Analyses

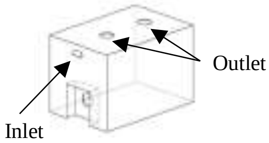
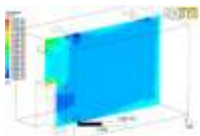
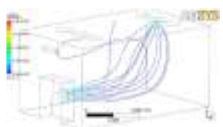
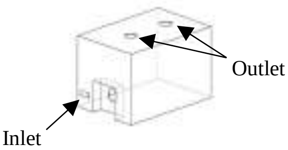
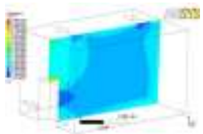
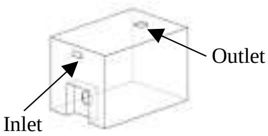
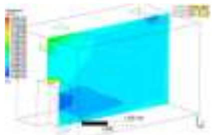
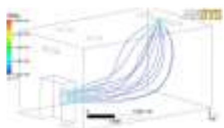
The experiment was conducted using a completely randomised design (CRD) with three replications. Analysis of variance (ANOVA) and Duncan Multiple Range Test (DMRT) for mean separation were used to detect significant differences among transportation mode and storage duration. Data were analysed using Statistical Analysis System (SAS) version 9.3 (SAS Software Institute, Cary, NC, USA).

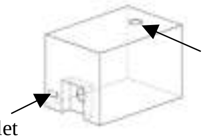
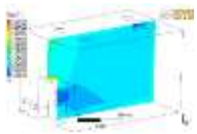
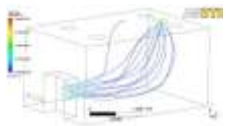
3. Results

3.1. CFD Simulation and System Modification

Comparison of the temperature and airflow distribution plots between configuration without inlet and outlet versus configuration with inlet and outlet at the evaporative-cooled storage unit is presented in Table 1. Five (5) different configurations with inlet and outlet(s) were investigated. From the result obtained, the configuration of one air inlet (front - lower left) and two air outlets (top – front and back centre) of the storage unit was seen to provide the optimum temperature and airflow distributions. As such, the configuration was then applied in the storage unit modification for further performance study.

Table 1. Comparison of the temperature and airflow distribution plots between configurations without and with inlet and outlet

Configuration		Temperature distribution	Airflow distribution
1: Without inlet and outlet			
2: One inlet at the top-centre with two outlets			
3: One inlet at the bottom-left with two outlets			
4: One inlet at the top-centre with one outlet			

Configuration		**Temperature distribution**	**Airflow distribution**
5: One inlet at the bottom-left with one outlet			

Temperature distribution plot: Red (High temperature); Blue (Low temperature)

3.2. Modified System Functionality and Performance Study

The truck battery (DC 24 V) was capable to power the modified systems comprised of an evaporative cooling and data monitoring system (AC 200–240 V) via a power inverter. In this research, a stand-alone truck battery was used for the power supply. However, future applications in a truck equipped with an evaporative cooling system will implement the use of the truck alternator to continuously charge the truck battery to supply power to the system.

The performance of the modified system was evaluated in terms of the cooling profile (temperature and relative humidity) inside the storage unit and further compared with the cooling profiles of the canvas and cold trucks. The cooling profile of the three short-term storage treatments during transportation from Cameron Highlands to Serdang is presented in Figure 3. The average temperature inside storage unit for the duration of the experiment was T3 (14.9 ± 1.9°C) < T1 (19.9 < ± 2.2°C) < T2 (25.1 ± 1.7°C). In this study, the evaporative-cooled truck exhibited an average temperature reduction($\Delta T_{average}$) of 10.1 ± 3.8°C from the ambient condition. It also demonstrated that the RH of storage unit was > 90%.

The weight and quality of choy sum for the fresh market that underwent the three treatments for five hours were assessed before and after the short-term storage during transportation. Post-five-hour storage treatments, the vegetable stored under T1 exhibited the least weight loss (% fresh weight basis) as compared to T2 and T3 (T1 < T3 < T2) (Figure 4). All the treatments demonstrated weight loss of < 3%.

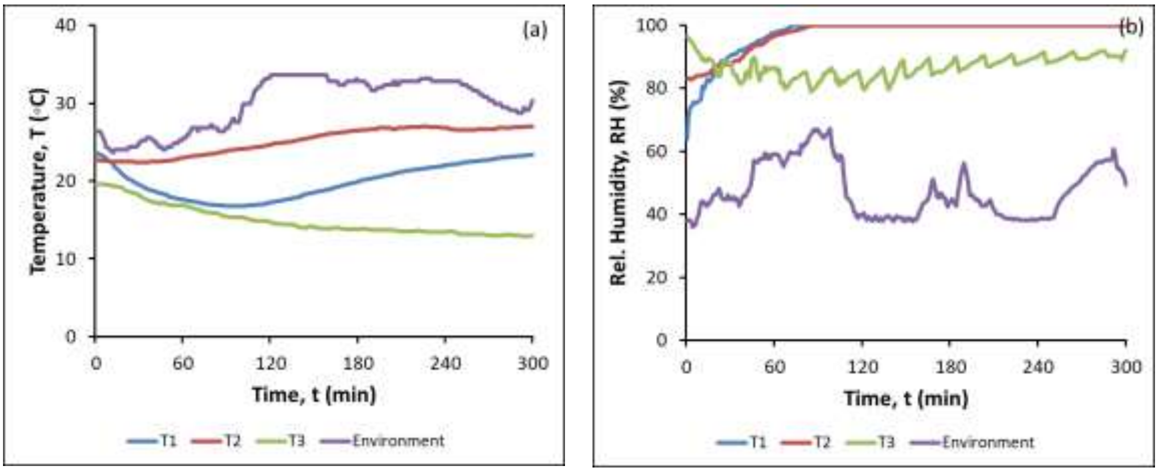


Figure 3. The plot of (a) T, and (b) RH against time between environment (out) and storage treatments. T1, T2, and T3 represent evaporative-cooled truck, canvas truck, and cold truck, respectively

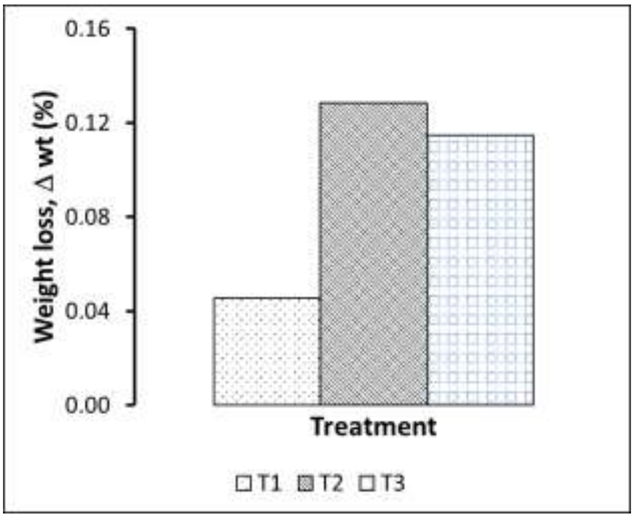


Figure 4. The plot of weight loss against storage treatments

The calculated saturation/cooling efficiencies for evaporative-cooled truck during transportation from Cameron Highlands to Serdang are presented in Figure 5. The calculated average, maximum, and minimum saturation efficiencies for the evaporative-cooled truck were 96.91%, 98.15%, and 67.25%, respectively. The minimum saturation efficiency basically occurred in the later process of evaporative cooling where there was narrow differential gap between the dry bulb and wet bulb temperatures. Nevertheless, the saturation efficiency predominantly reached above 95.00% throughout the transportation.

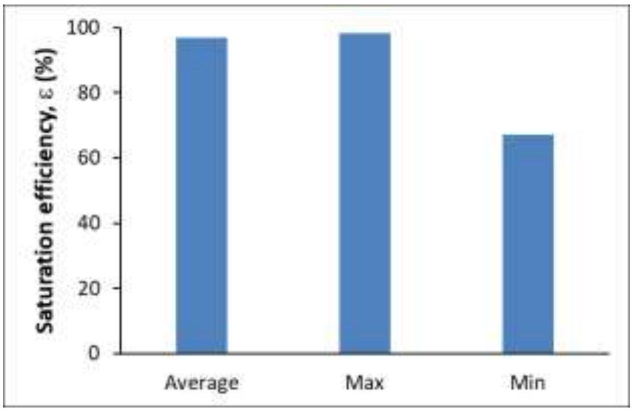


Figure 5. The calculated average, maximum, and minimum saturation efficiencies for evaporative-cooled truck

3.3. Postharvest Quality Analysis

Table 2 presents the effects of different treatments on the quality appearance of choy sum during storage at 5°C. In terms of visual appearance, both leafy vegetables transported using evaporative-cooled truck and cold truck maintained better freshness and overall acceptance for up to 15 days in the cold room as compared to canvas truck. There was no significant difference observed among treatments in leaf colour, and wilting of leaf and stem. During storage in the cold room, the quality appearance of the leafy vegetable to decreased over time. The leaves remained fresh and marketable until 11 days of storage but started to show signs of yellowing, stem wilting, and deterioration at day 15 of storage.

Table 2. The effects of different treatments on the quality appearance of choy sum during storage at 5°C

Main factors	Freshness	Leaf colour	Leaf wilting	Stem wilting	Overall acceptance
Treatment (T)					
T1	1.50^{b}	1.43	1.37	1.07	1.20^{b}
T2	1.80^{a}	1.53	1.53	1.27	1.43^{a}
T3	1.50^{b}	1.40	1.43	1.00	1.27^{ab}
F-Test Significant	*	ns	ns	ns	*
Storage Day (D)					
0	1.00^{d}	1.00^{c}	1.00^{c}	1.00^{b}	1.00^{c}
5	1.22^{cd}	1.00^{c}	1.17^{c}	1.00^{b}	1.11^{bc}
8	1.50^{bc}	1.00^{c}	1.17^{c}	1.00^{b}	1.11^{bc}
11	1.67^{b}	1.39^{b}	1.61^{b}	1.11^{b}	1.28^{b}
15	2.56^{a}	2.89^{a}	2.28^{a}	1.44^{a}	2.00^{a}
F-Test significant	**	**	**	*	**
Interaction T*D	*	ns	**	ns	ns

Means separation within columns and main effect by Duncan's Multiple Range Test at $p \leq 0.05$

ns, *, ** non-significant or significant or highly significant at $p \leq 0.05$, respectively

Table 3 presents the effects of different treatments on the chemical properties of choy sum during storage at 5°C. There was no significant difference in TSS, pH, and TTA values of leafy vegetable among the treatments except for AA content Evaporative-cooled and cold trucks showed a higher value of AA content as compared to the canvas truck. Besides, there were significant effects on the chemical data of leafy vegetable during the storage period. The chemical data of leafy vegetable slightly reduced and started to deteriorate after 15 days of storage period.

Table 3. The effects of different treatments on the chemical properties of choy sum during storage at 5°C

Main factors	TSS (°Brix)	pH	TTA (% citric acid)	Ascorbic acid content (mg/100g FW)
Treatment (T)				
T1	4.64	6.15	0.129	35.91^{a}
T2	4.70	6.14	0.125	33.12^{b}
T3	4.64	6.15	0.126	35.21^{ab}
F-Test Significant	ns	ns	ns	*
Storage Day (D)				
0	5.12^{a}	6.10^{c}	0.158^{a}	44.27^{a}
5	4.93^{ab}	6.00^{d}	0.130^{b}	35.06^{b}
8	4.37^{bc}	6.18^{b}	0.125^{b}	34.34^{b}
11	4.31^{c}	6.22^{a}	0.123^{b}	30.36^{c}
15	4.55^{bc}	6.24^{a}	0.100^{c}	29.51^{c}
F-Test significant	*	**	**	**
Interaction T*D	*	ns	*	**

Means separation within columns and main effect by Duncan's Multiple Range Test at $p \leq 0.05$
ns, *, ** non-significant or significant or highly significant at $p \leq 0.05$, respectively

4. Discussions

4.1. CFD Simulation and System Modification

The advancement of ICT applications in agriculture has enabled farmers to acquire huge amounts of site-specific data of their farms to assist and improve the decision-making process. CFD is a numerical modelling technique that can offer an effective way of accurately quantifying the influence of variable design options within a virtual environment to reduce the amount of physical experimentation. CFD is a computer simulation method that has been proven to be able to efficiently estimate both spatial and temporal parameters such as temperature and airflow. The method has proven its effectiveness in system design and optimisation processes within many industries (Bartzanas *et al.*, 2004; Lee *et al.*, 2013). CFD has received extensive attention throughout research institutes and the industrial community and became an important aspect of the engineering design and analysis environment of many industries due to its ability to predict the performance of new designs before the actual or physical development and implementation.

The CFD simulation results (Table 1) demonstrated, in the case of configuration 1 (without inlet and outlet), that the evaporated cold air from the evaporative cooler is circulating inside the storage unit. The lower temperature air from the evaporative cooler reduced the temperature inside the storage unit (showing in dark blue colour). However, as the cold air from the evaporative cooler consisted of high moisture content, and there is no air outlet at the storage unit, it caused the accumulation of moisture inside the storage unit and increased the humidity that will lead to the condensation problem. In the case of configurations 2, 3, 4, and 5 in which there were inlets and outlets added to the storage unit, the air with high moisture content flew out from the storage unit through the outlet, and reduced the humidity inside the storage unit. Additionally, the air flowing through the inlet enhanced the air exchange rate between the storage unit and the environment. However, as the environment temperature was higher as compared to the temperature inside the storage unit, installation of the inlet caused hot air from outside to flow into the storage unit hence the temperature inside the storage unit increased. This is shown in the temperature contour plot where the total area with a temperature of less than 29°C was 92%, 72%, 71%, 70%, and 70% for configurations 1, 2, 3, 4, and 5, respectively.

The flow of air from the outside increased the airflow inside the storage unit. Higher airflow reduced the relative humidity in the storage unit by pushing out the high moisture content air from the storage unit through the outlet. As a result, the lower relative humidity increased the efficiency of the evaporative cooling system. From the streamline plot, the areas with airflow rate of less than 0.1 ms^{-1} was 60%, 29%, 25%, 29% and 28% for configuration 1, 2, 3, 4, and 5, respectively. From the simulation results, it can be concluded that the configuration with one outlet produced higher temperature as compared to two outlets configuration. The cold air from the evaporative cooler was more evenly distributed in the two outlets configuration. Similarly, in the streamline plot, the cold airflow was more evenly distributed in the two outlets configuration. Therefore, from the CFD simulation results, it was concluded that configuration 3 (inlet placed at the front - lower left together with 2 outlets on top – front and back centre of the storage unit) was the most optimal condition with a good balance between temperature (71% area with temperature less than 29^{o}C) and airflow (only 25% area with an airflow rate of less than 0.1 ms^{-1}) distributions and hence, applied in the storage unit modification. The modified system was then evaluated its performance in the subsequent study.

4.2. Modified System Functionality and Performance Study

In general, the evaporative cooling system can reduce storage temperature ~10°C less than ambient temperature, and increase relative humidity to >90%, based on the environmental conditions (Dadhich *et al.*, 2008; lal Basediya *et al.*, 2013). Mordi and Olorunda (2003) reported on a temperature reduction (8.2°C from the ambient temperature of 33.0°C) and relative humidity increment (36.6% from the ambient relative humidity of 60.4%) in the evaporative-cooled storage of tomatoes . Similarly, the results obtained in this study (Figure 3) are in agreement with the recommended temperature reduction, and relative humidity for evaporative cooling storage.

Burbade and co-workers (2017) observed that fruits and vegetables stored at the evaporative cooling chamber for a certain duration had minimum significant loss and hence, beneficial for a marginal farmer. It was observed that the weight loss of tomatoes was 52% in ambient condition whereas it was 28% in the evaporative cooling storage structure. Besides, the overall cooling efficiency of the evaporative cooling storage was found to be 89.97%. Chinenye and co-workers (2013)discovered that the developed evaporative cooler was able to reduce the cooler temperature close to the wet-bulb temperature of the ambient and increase the relative humidity to 96.8%. It was tested with highly respiring cut pumpkin and amaranthus leaf and achieved favourable temperature and relative humidity for safe storage for 8 days. At an ambient temperature of 37.0°C, the evaporative cooler provided the storage conditions of 23.2°C, and 85.6%–96.8% relative humidity, which enhanced the shelf life of a wide range of fruit and vegetables with the power consumption of the cooler that was half of a typical vapour compression refrigerator of the same volume. Higher relative humidity is proven to be beneficial for leafy vegetables to prevent moisture loss and keep the vegetables hydrated during storage.

In the case of weight reduction/loss post-five-hour storage treatments, the least weight loss exhibited by leafy vegetable stored under T1 treatment might be due to the combination of low temperature and high relative humidity exhibited in the treatment. Fresh vegetables constantly lose water to the environment after harvest resulting in weight loss. Visible wilting or shrivelling may be observed when vegetables lost 3–5% of their fresh weight (Kader, 2002). However, in this study, no significant visible wilting or shrivelling was observed post-five-hour storage treatments since all the treatments exhibited <3% weight loss.

On the other hand, the saturation/cooling efficiency for evaporative-cooled truck results attained in this study are in agreement with other researches. The efficiency of a single evaporative cooling was reported 85–95% (Jain, 2007). The application of cellulose material (thickness of 4 inches) produced the highest saturation efficiency of approximately 92.8% while khus-grass material resulted in the lowest saturation efficiency of approximately 40.13% (Khobragade & Kongre, 2016). The higher the difference between the dry bulb and wet bulb temperature, the more effective shall be the evaporative cooling system. On the test day, the temperature in the evaporative-cooled truck was varied between 16.8°C to 23.7°C as compared to ambient temperature variations between 23.7°C to 33.6°C.

4.3. Postharvest Quality Analysis

The freshness of fruits and vegetables is a very important factor for the consumer to purchase and consume these commodities (Péneau *et al.*, 2006; Péneau *et al.*, 2009). Wilting and yellowing of leafy vegetables are the major contributing factor to consumers' dissatisfaction.

In this study, the results showed that evaporative-cooled and cold trucks maintained the freshness and overall acceptability of leafy vegetable studied. The cold temperatures of the evaporative-cooled truck and cold truck were able to keep the freshness of leafy vegetable during transportation. Temperature control is the most important factor in maintaining product quality especially for leafy vegetables that should always be cooled as soon as possible after harvest to protect the quality, reduce weight loss and extend shelf life (Kitinoja & Kader, 2015). Leafy vegetable transported using evaporative-cooled and cold trucks had a slightly higher value of AA content as compared to produces transported using the canvas truck. Evaporative-cooled truck treatment had the highest AA of leafy vegetable, followed by cold truck and canvas truck. The cold truck had the lowest temperature (10°C) in the storage unit during transportation of the leafy vegetable. Temperature management after harvest is the most important factor to maintain vitamin C of fruits and vegetables; losses are accelerated at higher temperatures and with longer storage durations (Lee & Kader, 2000).

The postharvest quality of leafy vegetables was significantly affected during the storage period. Leaves' freshness, wilting, and yellowing decreased in palatability after 15 days of storage. Ferrante and co-workers (2004) reported on the loss of green colour and appearance of yellow colour in green leafy vegetables when browning, chlorophyll, and carotenoids degradation takes place during storage. Physicochemical quality gradually decreased during the storage period. The reduction of TSS, TTA, and AA content of leafy vegetables during storage was probably due to the slowing down of respiration and metabolic activity, hence leading to the senescence process. In this regard, slower respiration may slow down the synthesis and use of metabolites resulting in lower TSS due to the slower change from carbohydrates to sugars (Taşdelen & Bayindirli, 1998). In the present study, the titratable acidity and pH of leafy vegetables differed significantly over the storage period. A gradual decline in the titratable acidity and increases in pH value was noticed during storage duration. During storage, the fruit itself might utilise the acid hence the acid in the fruits decreased and resulted the reduction of citric acid (Bhatnagar *et al.*, 2006). Similarly, fruits and vegetables show a gradual decrease in AA content as the storage temperature or duration increases (Adisa, 1986).

Even though the storage during the transportation is only for short-term, the effects of the transportation mode played a significant factor in maintaining the quality of the leafy vegetables for subsequent storage in the market.

5. Conclusions

The modified evaporative-cooled truck for short-term storage of vegetable during transportation exhibited good functionality, cooling profile performance, saturation/cooling efficiency, and leafy vegetable (choy sum) quality for the fresh market. The configuration providing the optimum temperature and airflow distributions in the storage unit from the CFD simulation study was applied in the system modification. The five-hour cooling profile exhibited the average temperature inside the storage unit was T3<T1<T2. The evaporative-cooled truck exhibited average temperature reduction, $\Delta T_{average}$ of 10 ± 3.8°C from the ambient condition, and demonstrated relative humidity of >90%, which was in agreement with recommended relative humidity for leafy vegetable storage. Leafy vegetable stored under T1 exhibited the least weight loss (% fresh weight basis) as compared to the other treatments. The application of evaporative-cooled truck during vegetable transportation provided positive effects towards vegetable quality up to two weeks storage at 5°C.

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