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Development and evaluation of innovative vehicle body cooling attachment for transportation of tomato

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Abstract
Vehicle involved in transportation of fruits and vegetables, body cooling attachment based on cooling principle was developed and assessed its performance in terms of decrease in air temperature, increase in relative humidity, saving in physiological loss in weight, increase shelf life and economic gain. The developed vehicle cooling attachment comprises of cooling unit, vehicle body attachment, air-duct and water circulation system. Freshly harvested tomato crates loaded directly into chamber from farmer's field. Inside the attachment temperature and relative humidity was maintained 27.80±1.44 °C and 62.81±3.98% against ambient condition of 37.88±1.55 °C and 26.44±4.20%. The inside temperature reduced by 10.08±3 ºC and humidity maintained above 60% than the ambient. The saving in physiological loss in weight and shelf-life of tomato was 2.35% and 3 days over control, respectively. The developed cooling attachment can be assembled over vehicle body and disassembled when required.

Keywords: Vehicle cooling attachment, tomato transport, two-stage evaporative cooling, shelf life, saving in loss of weight

Introduction
India is leading producer of fruits (102.48 MMT, 2020-21) and vegetables (200.45 MMT, 2020-21) in the world but on the other side, the wastage of harvested produce is very huge due to lake of cool supply chain facilities and in adequacy of post-harvest infrastructure as per report of NABARD Consultancy Services. As per report post-harvest losses for selected fruits and vegetables reported in the range of 6- 16% and 6.9 - 13%, respectively. Tomato being the most perishable percent among vegetables accounts for 2459114 Metric ton and Rs.59.21 billion loss (NABCONS 2022) [10].
Large quantities of fruits and vegetables are being transported to various parts of the country through mini, medium and big size truck vehicles, which leads to loss at end point, because of higher ambient temperature and lower relative humidity increases the physiological function of respiration of fruits and vegetables to their surrounding environment. The respiration of produce mainly depends on surrounding temperature and humidity. Refrigeration based transportation is used for high valued perishable products/commodities, but it is costly both in construction and operation and also non-eco-friendly, hence limits its use for less valued fruits and vegetables. Use of evaporative cooling or its combination with other such cooling technologies should be worked out for economical feasible cold chain for country (Patil, 2014) [11].
Evaporative cooling also known as direct cooling is the most efficient method for cooling fruits and vegetables in dry and hot conditions. It has already been proven to be an effective method of storage of fruits and vegetables, being simple in design, easy to fabricate requiring low investment, no energy requirement, environment benign (Das and Chandra, 2001; Jha, 2008; Basediya *et al*., 2013, Mansuri *et al*., 2016) [3, 8, 1, 9]. To improve the efficacy of direct type evaporative cooling system, scientists have worked on it's by changing the design, process, materials and combining with indirect type cooling system (Vala 2018) [14]. They reported that in the region where wet bulb temperature is low; indirect and direct evaporative cooling greater cooling with comfort conditions similar to refrigerated systems. Dutta *et al*., 1987 [4], Jain and Hindoliya, 2012 [7], have fabricated and tested two-stage indirect-direct evaporative cooler with three different shapes and three different cooling

materials and reported overall efficiency of 119%. They also reported that the two-stage evaporative cooling system will be suitable for climatic conditions of 39 °C-46 ºC dry bulb temperature and 37%-46% relative humidity. Such a system is found to be better for hot and humid climates (Heidarinejad et. al., 2009) [5]. The overall effectiveness of the combined indirect-direct cooling system is more than the individual single systems, (Jain 2007) [6]. In this study, an indirect type cooling system combined with direct type evaporative cooling system (known as two-stage evaporative cooling system) was used.

For transport of less valued fruits/vegetables, a low-cost effective cooling system for vehicle is the need of hour for countries like India, where hot and dry weather prevails significantly during the year. Many researchers have worked on storage of fruits and vegetables using direct type evaporative cooling systems. However, application of evaporative cooling technology in transportation vehicle for short-term storage is still lacking. In view of this, a study was undertaken to develop vehicle cooling attachment for short-term storage management of vegetables during transportation.

Materials and Methods

Conceptualization

For the conceptualization of the two-stage evaporative cooling attachment TATA ACE mini truck was selected. By considering dimensions of the vehicle body a conceptual design was prepared. All the components and its arrangement within the vehicle are shown in Figure 1. The vehicle cooling attachment consists of cooling unit, the vehicle body, a cool-air distribution duct and a water circulation system shown in figure 2.

The cooling unit (900x645x200 mm) is consisted of two cooling systems; indirect cooling (finned tube heat exchanger type) and direct cooling (wet-pad CELdek evaporative cooling). Both cooling systems are put together in holder to work as a single unit. The indirect cooling system placed first, followed by the direct cooling system. The entering air is first cooled by the indirect cooler and then the air is passed through wet-pad cooler. Water continuously circulated using a small battery operated submersible pump placed in water tank.

The body attachment (2180x1450 x 1550 mm) was fabricated and mounted over the vehicle body, making it close chamber. The walls of the body attachment were made insulated by placing one inch thick thermocol (Polystyrene) sheet in a sandwich type configuration. The bottom of the vehicle body was also made insulated by placing thick (19mm) ply by fixing galvanized iron sheet over it. Two side open able doors were provided with the body attachment for loading and unloading of vegetables. Body attachment fabricated in such a way that it can be mounted over the vehicle body using nut bolt.

Considering the air flow entering in cooling unit at constant vehicle speed (45±5 kmph), an air duct was fabricated (galvanized iron sheet) and fitted with cooling unit (Fig.1). For uniform distribution of cooled air inside the vehicle body attachment, three parallel duct having opening at regular intervals were provided. The duct was fitted inside the top of closed chamber.

For continuous supply and re-circulation of water in the cooling system, a water tank (capacity 30lit.) provided at one side of the vehicle. A small submersible water pump (Voltage: 160-240/50Hz, power: 12W, Head Maximum: 1.65m & discharge: 900lph) with necessary PVC piping was arranged for the distribution of water in both the cooling systems, as shown in Figure 1.

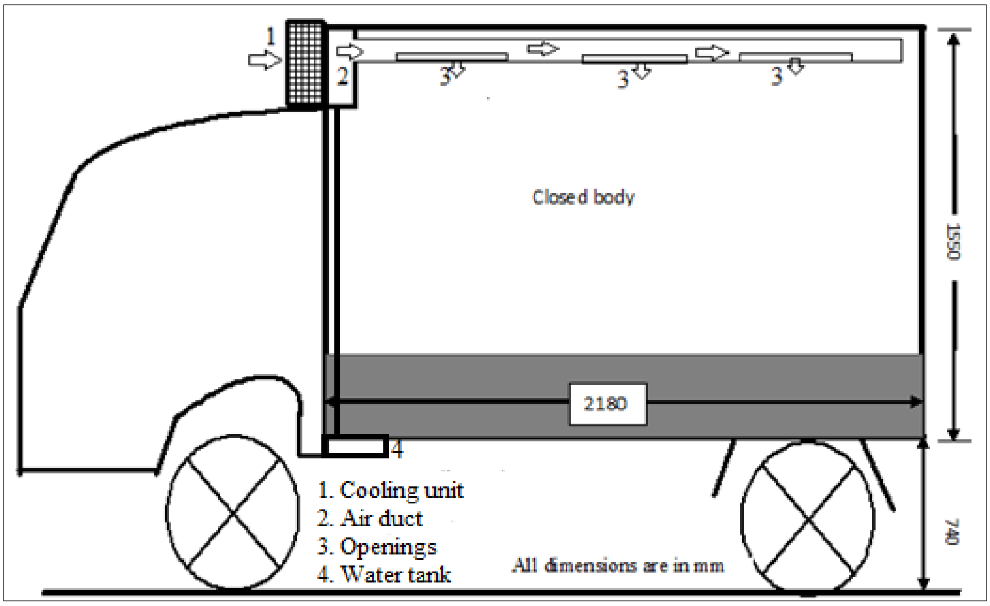

Fig 1: Conceptual diagram

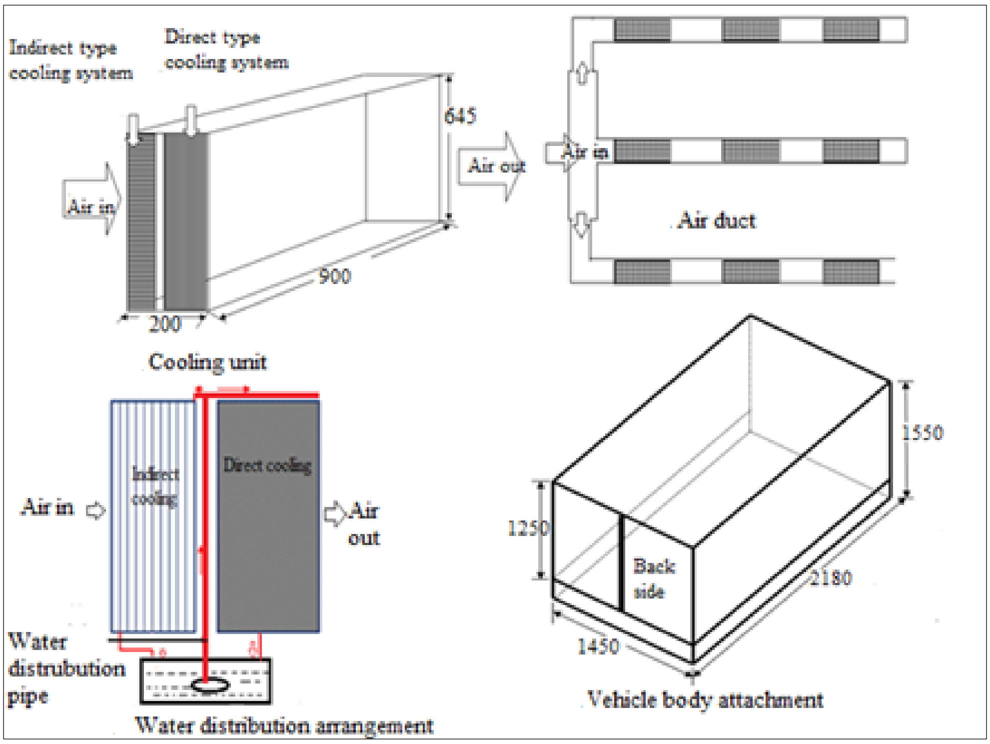

Fig 2: Conceptual diagram and cooling attachment components

Performance evaluation
All the components fitted with main vehicle body to work as a single cooling attachment. The cooling attachment was placed over the vehicle body, fixed with nut bolt and made air tight. The storage space was made completely air tight by closing doors. The vehicle was tested for proper functioning of the all the components, before loading the tomatoes. Freshly harvested tomato crates were loaded directly from farmer's field (Fig. 3) and vehicle run on road. The performance of the developed cooling attachment was evaluated in terms of the decrease in temperature and increase in humidity inside the closed chamber, saving in PLW, shelf life, and techno-economic feasibility.

Techno-economic feasibility
Cost estimation of the developed vehicle cooling attachment system was done to determine the feasibility of its use. Cost economics worked out considering the fixed cost and variable cost (Dabhi and Davra, 2017, Singh et. al., 2023). The total cost of developed cooling attachment including the cost of the brought-out items worked out and payback period worked out considering saving in weight of tomato per trip.

Fixed cost of the system, Rs = (cost of the system)/ (useful life × working days)

Operating cost= $(\text{cost of the system} - (2\% \times \text{cost of the system}))/(\text{useful life})$

Power Cost = KWh ×Rate

Total cost = fixed cost + operating cost + power cost

Fig 3: Loading of tomatoes in vehicle

Results and discussion

Decrease of temperature and increase in humidity inside the body attachment

Observed data for variation in temperature and relative humidity inside the vehicle cooling attachment is shown in figure 4. The average mean temperature inside the chamber was maintained at 27.80±1.44 °C as against the outside temperature of 37.88±1.12 °C with mean temperature drop of 10.08±3 ºC, whereas mean 62.81±3.98% relative humidity was maintained as against outside average relative humidity of 26.44±2.16%. The average percentage increase in humidity was 141.83%. The overall effectiveness of the system observed 67.7%.

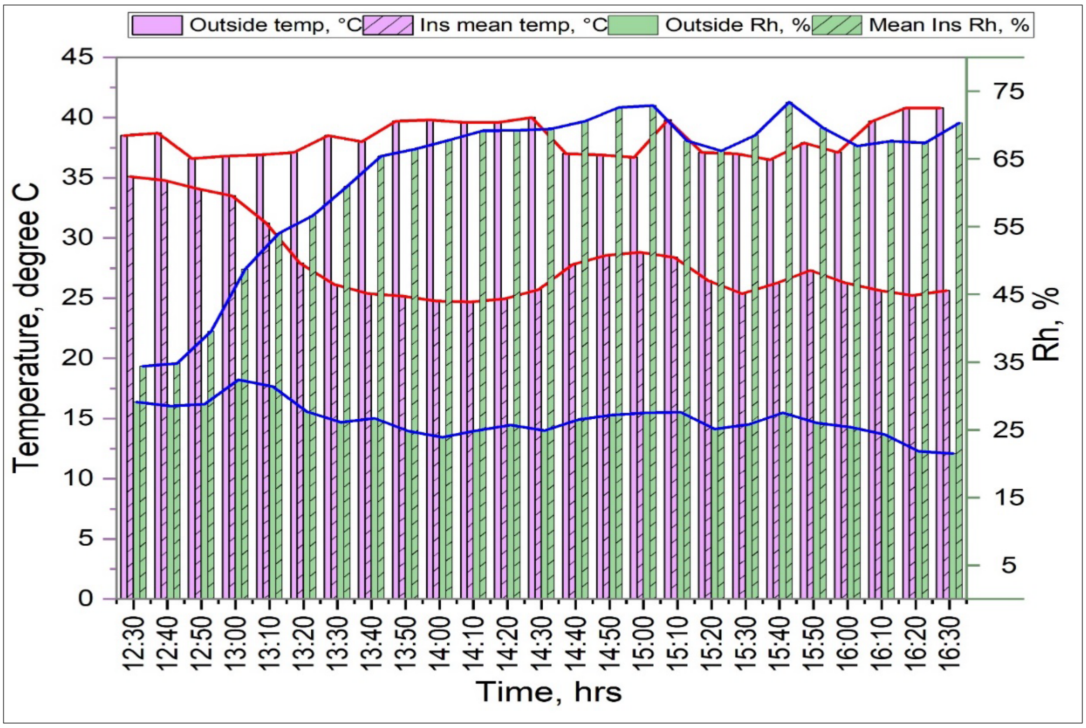

Fig 4: Variation in temperature and relative humidity inside vis-a-vis outside

Saving in PLW: Tomatoes were sorted, cleaned and weighed before loading. Two samples were prepared for both the control and storage body chamber and they were weighed before and after the run Fig 3. The physiological loss in weight and saving in PLW over control transport calculated by the difference between the initial weight and end weight and it was expressed as percentage. The saving in physiological loss in weight over control was 1.98%. The saving was due to lower temperature and higher humidity provided to the tomato during transport.

$$\text{Physiological loss in weight,\%} = \frac{(\text{Final weight} - \text{Initial weight})}{\textit{Initial weight}}\ x\ 100$$

Saving in PLW over control, (%) = [PLW with control (%) – PLW with cooling attachment (%)]

Increase in shelf life

The shelf life was decided based on its appearance and spoilage. When 40% of tomato showed symptoms of shrinkage/spoilage that was considered to have reached the end of shelf life 9rai *et al*., 2012). Both the samples transported in vehicle cool attachment and control were kept in room immediately at the end of run for storage study The shelf-life of the tomatoes transported in vehicle cool attachment was observed three day more as compared to control. Shelf-life envisaged due to less respiration during transport.

Cost economics

The total cost of developed cooling attachment including the cost of the brought-out items is as per Table 1. The market price of tomato on the day of trial was considered for saving in term of rupees, and the final pay-back calculated based on numbers of trips (Table 2). Worked out cost economics are as follows:

Table 1: Costing of the developed vehicle body cooling attachment

Sr. No.	Name of components	Cost (Rs)
1	Main vehicle body: Wall made of sandwich 1 inch thermo coal insulation using mild steel and galvanized iron sheet	85000.00
2	Air distribution duct	8650.00
3	Cooling unit holder for holding cooling systems	5000.00
4	Cooling system (i) Indirect type cooling system made of copper tube and aluminium fins with top and bottom support (ii) Direct type cooling system made of cellulose CELdek pad 200mm thick, 6 ft.	17800.00 2400.00
5	Water distribution system: pipes, pipe fittings, water pump, etc	3000.00
	Total (Rs.)	121850.00

Fixed cost

Assumptions:

- Useful life of the cooling attachment system = 15 years
- Total working days = 280 days
- Depreciation and maintenance cost = @ 2% of total cost/year

fixed cost of the system, Rs= $121850/(15 \times 280)$
= 29.00/day
= Rs 4.83/ trip

Operating cost = $(121850 - 2437)/15$
= Rs 7960/year
= Rs 4.75 / trip

Power cost (0.045 KWh) = 0.36 Rs/h
= Rs 1.44/trip

Total cost= 4.83 + 4.75 + 1.44
= Rs 11/trip

Saving

Table 2: Saving in Physiological loss in weight (PLW) over control, benefit and break-even point.

Vehicle cooling attachment transport system		Control transport	
Initial weight of loaded tomatoes (kg)	Final weight of tomatoes after trip (kg)	Initial weight of loaded tomatoes (kg)	Final weight of tomatoes after trip (kg)
906.402	888.726	895.75	851.94
Diff= 17.68		Diff= 43.81	
PLW, (%) = $\frac{906.402 - 888.726}{906.402}$ = 2.91%		PLW, (%) = $\frac{895.75 - 851.94}{895.75}$ = 4.89%	

- Percent saving in PLW over control, (%) = 1.98%
- Saving in PLW /trip = 26.13 kg say 26 kg
- Saving in Rs/trip* = 260
- Benefit per trip = Rs 249
- Break-even point = 490 (trip)
- Shelf-life benefit = 3 days over control
- (* Wholesale market rate Rs 200/20kg.)

Conclusions

The cooling attachment can be designed as per vehicle body storage volume. The developed attachment maintained a temperature 10.08±3 ºC lower than the ambient temperature and humidity levels more than 60% (62.81±3.98%) during transport resulted in percent saving in physiological loss in weight 2% and shelf life of 3 days over control. The cost of saving was Rs 260 per trip, and break-even point can be reached after 490 trips. The developed system can play important role in cool supply-chain of fruits and vegetable helping to narrow the demand-supply gap. The developed cooling vehicle attachment is simple in design, low cost, effective, can be easily fitted and removed from the vehicle body as and when required. The cooling component alone can also be fitted with an existing closed vehicle body. The costing of the vehicle cooling attachment system varies with volumetric capacity of the system.

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