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Precooling of table grapes on a commercial scale as function of packaging[1]

Pré-resfriamento de uvas de mesa em escala comercial em função das embalagens

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HIGHLIGHTS:
Temperature heterogeneity along the airflow direction in a pallet was identified.
Cooling effects in polystyrene and cardboard packaging were the same.
Relative humidity in the cooling room and the percentage of package openings were inadequate.

ABSTRACT: Although precooling by forced air is widely used to remove field heat from fresh table grapes, there is no knowledge about its use and efficiency. Factors influencing the process include temperature and relative air humidity, amount and initial temperature of the fruits, air velocity, and packaging. The objective of this study was to evaluate the cooling effect and efficiency of forced air cooling on table grapes in two types of packages. The experimental method used randomized blocks, in a 2 × 3 factorials, corresponding to two package types (polystyrene and cardboard) and three heights on the pallet - lower, middle, and upper - with four replicates. The temperature gradient in the direction of the airflow was evaluated. There was heterogeneity in cooling, both vertically and horizontally, on the pallets with a central heat zone for both the directions. None of the packages was suitable for fast cooling as both types of packages showed a cooling time of 15.5 h; moreover, relative humidity values were far below the ideal value for table grapes.

Key words: ambient, cold chain, packing house, postharvest

RESUMO: Embora o pré-resfriamento por ar forçado seja amplamente utilizado na remoção do calor de campo de uvas de mesa frescas, muitas vezes não há conhecimento sobre seu funcionamento e eficiência. Fatores como temperatura e umidade relativa do ar, quantidade e temperatura inicial das frutas, velocidade do ar e embalagens, influenciam o processo. Objetivou-se neste estudo avaliar o efeito e eficiência do resfriamento de uvas de mesa sujeitas a resfriamento por ar forçado. O delineamento experimental foi em blocos casualizados, em um fatorial 2 × 3, correspondente a dois tipos de embalagens e três alturas no pallet: inferior, meio e superior com quatro repetições. Foi avaliado o gradiente de temperatura no sentido do fluxo de ar. Há heterogeneidade de resfriamento tanto no sentido vertical quanto horizontal dos paletes, com uma zona de calor concentrada na região central em ambas as direções. Nenhuma embalagem apresentou design favorável ao resfriamento rápido, já que em ambas o tempo de resfriamento foi de 15,5 horas, além de valores de umidade relativa do ar muito abaixo do ideal para uvas de mesa.

Palavras-chave: ambiência, cadeia do frio, packing house, pós-colheita

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Introduction

Fruits, vegetables, roots, and tubers have the highest percentage of food losses with air temperature being the most influential factor in the deterioration of fresh produce and market life, resulting in financial losses due to reduced quality and rejection by consumers (Goedhals-Gerber & Khumalo, 2020).

The temperature control of sensitive products through the cold chain is a daily essential requirement worldwide. Interlinked processes are used to ensure high food quality to consumers (Mataragas et al., 2012; Laguerre et al., 2013; Todd, 2017; Badia-Melis et al., 2018).

Forced air precooling is widely used for removing field heat, thus, reducing crop metabolic activity and maintaining high nutritional quality for consumers. However, in commercial operations, there is often no knowledge about the effect and efficiency of forced air cooling technology as it is largely influenced by several factors, such as air temperature and relative air humidity in the cooling room, quantity and initial temperature of the fruits, as well as package material, size, and design (Berry et al., 2017).

In addition, there is limited information about the effect and efficiency of commercial forced air cooling on fruit packages at different positions in the pallet. Therefore, further studies are required to determine if the cooling system, compared to small-scale laboratory systems (Wu et al., 2018), works properly.

The objective of this study was to evaluate the effect and efficiency of forced air cooling on table grapes in two types of packages, polystyrene, and cardboard.

Material and Methods

The study was conducted in a forced air cooling room designed for table grapes in a commercial packing house located in Lagoa Grande, PE (08° 59' 49" S, 40° 16' 19" W and altitude of 300 m), Brazil. The experiment was performed during normal commercial operations using seedless table grapes harvested during the daytime. The ideal final cooling temperature was considered to be 0 °C and the relative air humidity between 90 and 95 % (Ardente et al., 2015).

The cooling room was 11.93 m, 5.10 m, and 3.36 m in length, width and height, respectively, with 16 bays for cooling the pallets. The cooling capacity was 54 TR (refrigeration ton), with a suction system composed of 8 0.50 m-diameter fans and a 2 hp three-phase WEG motor. These were connected to a "mother machine" that controlled the operation and defrosting timings, programmed to occur every 4 h for a duration of 40 min, during which the water injector nozzles continued to operate.

During packing house operation, the temperature and relative air humidity in the cooling room were monitored and controlled through sensors installed in front of evaporators and water nozzles. The sensors were interconnected to a Full Gauge® MT-512e 2HP controller, with control temperature ranging from -50 to 105 °C and relative air humidity from 10 to 90 %.

The experiment followed a randomized block design, with a 2 × 3 factorial scheme, corresponding to two types of packages and three different pallet heights: lower, middle, and upper (corresponding to 0.20, 1.05, and 1.91 m for the pallet with polystyrene boxes and 0.20, 1.16, and 2.04 m for the pallet with cardboard boxes), with four replicates.

Two types of commercial secondary packages used on the farm were evaluated, both with a 5 kg capacity (Figure 1). One type of package was produced from low-density expanded polystyrene (EPS Isopor®), with length, width and height of 0.6 m, 0.4 m, and 0.10 m respectively, and an effective opening percentage of 4.88 %. The other type was produced from single-wall corrugated cardboard with dimensions of 0.6 × 0.4 × 0.09 m and a percentage of effective opening of 1.72%, which facilitated the airflow through the package during cooling.

Inside these boxes were placed 10 polyethylene terephthalate (PET) clamshell containers that accommodated approximately 0.5 kg of grapes each, and these were wrapped in microperforated plastic bags with 1% openings. Five boxes were arranged in layers to build the entire pallet. Each pallet had 24 layers of cardboard boxes or 19 layers of polystyrene boxes.

Air temperature and relative air humidity were monitored by Onset HOBO® U12-013 data loggers (Onset Computer Corporation, Pocasset, MA, USA) with temperature measurement ranging from -20 to 70 °C with an accuracy of ±0.35 °C). Onset® thermocouples of model TMC6-HD (with a temperature measuring range of -40 to 100 °C and accuracy of ±0.25 °C) were also used to evaluate the temperatures on the opposite sides of the pallets, in addition to the middle region. This was done by measuring the temperatures at three points on the pallets (air flow inlet, middle of the boxes, and air flow outlet) at three heights to check the temperature gradient in the direction of the cold airflow. Before introducing the forced air cooling, the fruits were kept in a cold room at 13 °C.

The pallets were randomly distributed on the same side in the cooling room so that they were subjected to the same air suction. Data loggers were also installed and distributed along the walls between the pallets, at the entrance and at the bottom of the chamber, and in front of the pallets to monitor the air temperature and relative air humidity in the cold room.

The data were collected every minute and recorded by the data loggers during the period of operation of the forced air cooling room (18:00 to 09:30 h).

The results were submitted to analysis of variance and the Tukey test at $p \leq 0.05$, using SISVAR software version 5.6.

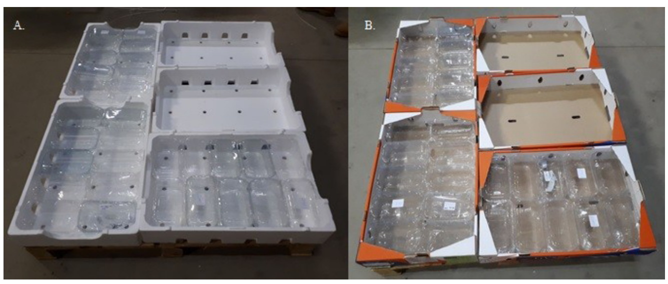


Figure 1. Arrangement of polystyrene boxes (A) and cardboard (B) on the pallet in the direction of air flow

Results and Discussion

During the entire cooling process, temperature nonuniformity was observed at the different heights of the pallets (Figure 2). The highest resistance to cooling was observed for the fruits that were in the boxes at middle height, whereas the boxes at the lower and upper heights presented similar cooling behavior but faster than the middle one. Defraeye et al. (2015b) and Delele et al. (2013) also observed the heterogeneity of cooling between the boxes located at different heights in the same pallet.

Uneven cooling can affect the quality of the fruits; hence, it is important to reduce temperature heterogeneity and promote uniform-quality customer products. In addition, the temperatures are commercially measured only in some positions of the pallets; therefore, the uniformity of cooling is of paramount importance to ensure that temperatures represent the entire load (Wu & Defraeye, 2018).

The heterogeneity of the cooling increases the loss of humidity from the surface of the fruits, which can vary up to 50% between the fruits located in the warmer and cooler regions of the package or pallet (Bishnoi & Aharwal, 2020). Consequently, there are physiological deteriorations, such as withering; reduced stiffness, turgidity, and juiciness; and a decrease in shelf life. These processes are directly influenced by fruit transpiration and the loss of oxidative carbon from the respiratory substrate in the form of CO_2 production (Bovi et al., 2018).

Baird et al. (1998) relate heat transfer to the product layer height. They state that as the layer height increases, warmer air pockets may be formed, generating dead zones where air renewal is reduced and heat transfer occurs by natural convection at a lower speed. This may explain the slower cooling effect at the medium height. Furthermore, Mukama et al. (2018) state that the middle layer may be exposed to less amounts of cold air owing to the heterogeneity of the airflow that comes in contact with the pallet.

Evaluating the temperature graphs in the direction of the airflow (Figure 3), it can be observed that the boxes in the middle of the pallet represent a zone of heat concentration when compared to the boxes located at the air inlet and outlet points in the pallets.

It can also be observed that in the pallet with the polystyrene boxes, the temperature values were higher at the air outlet point than those at the entry point; however, in the pallet with the cardboard boxes, the cooling curves of the two points were practically equal, and the central region of the box cooled more slowly with a temperature gradient of approximately 3 °C, when compared to the other evaluated positions. This can be explained by the passage of cold air through the side faces of the pallet and the proximity of these faces to the suction region of the cold air. This hindered

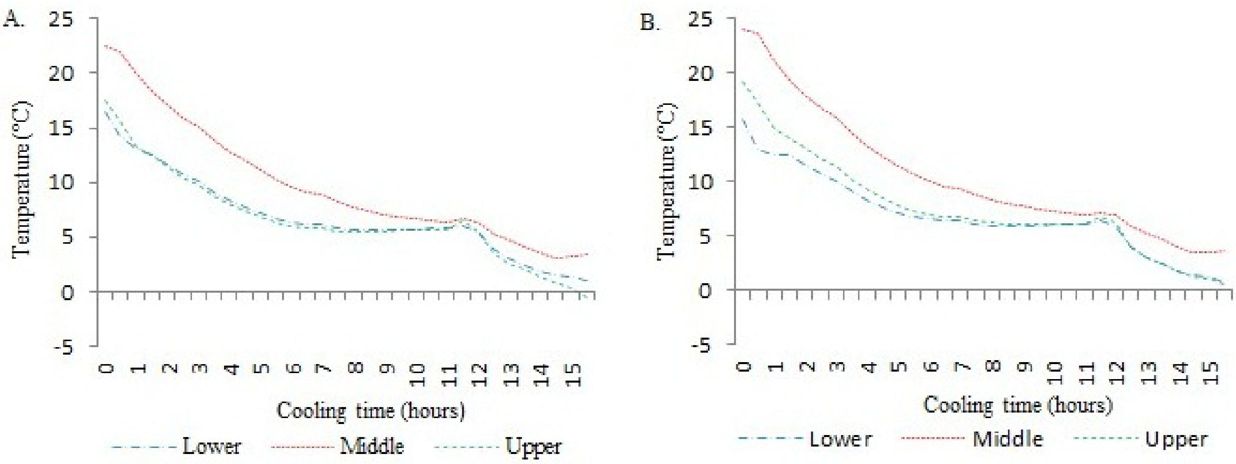


Figure 2. Air temperature as a function of cooling time at different heights within the same pallet: (A) pallet with polystyrene boxes and (B) pallet with cardboard boxes

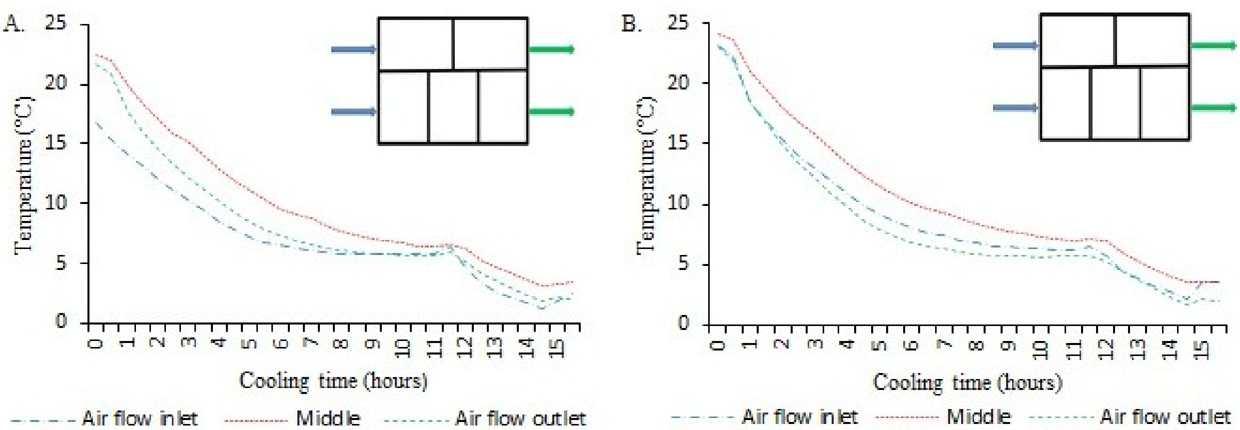


Figure 3. Air temperature as a function of cooling time at different positions in the pallet box layer (A) pallet with polystyrene boxes and (B) pallet with cardboard boxes

cooling in the larger part of the central region as the air did not pass unidirectionally.

This condition occurs in the dock type forced cooling room because there are spaces between the pallets allowing the passage of air through the sides. This is different from the Californian type forced cooling room, where all the pallets are lined up side by side and covered with a tarp that forces the flow of cold air unidirectionally, as described by Elansari et al. (2019).

Therefore, it is necessary to interweave the pallets to achieve uniform airflow, resulting in a more homogeneous cooling of the entire pallet and reducing the temperature differences between the different positions of the product in the pallet. One possible approach to accomplish this is to place the pallets in a position inverted from the usual; this would reduce the quantity of boxes through which the air flows. Thus, instead of three boxes, it would pass through a maximum of two, as suggested by Wu et al. (2018).

Wu et al. (2018) also suggested that the airflow should be inverted during cooling, which occurred as a routine operation where this experiment was performed, through the rotation of the pallets, making the previous air inlet face the air outlet and vice versa.

In the study involving forced air cooling of fruits with different geometries by Teruel (2001), it was observed that, depending on the location of the fruits in the layer, cooling occurred differently as the fruits in direct contact with the cold air cooled faster than the fruits less exposed — a condition also verified by Inestroza-Lizardo et al. (2016).

Mukama et al. (2018) observed that placing the pallet in contact with the airflow on the 1 m side, similar to the present study lowered the ventilation when compared to that in the 1.2 m orientation, resulting in a convective mass transfer coefficient from the fruit surface to the lower ambient air and, consequently, a longer cooling time.

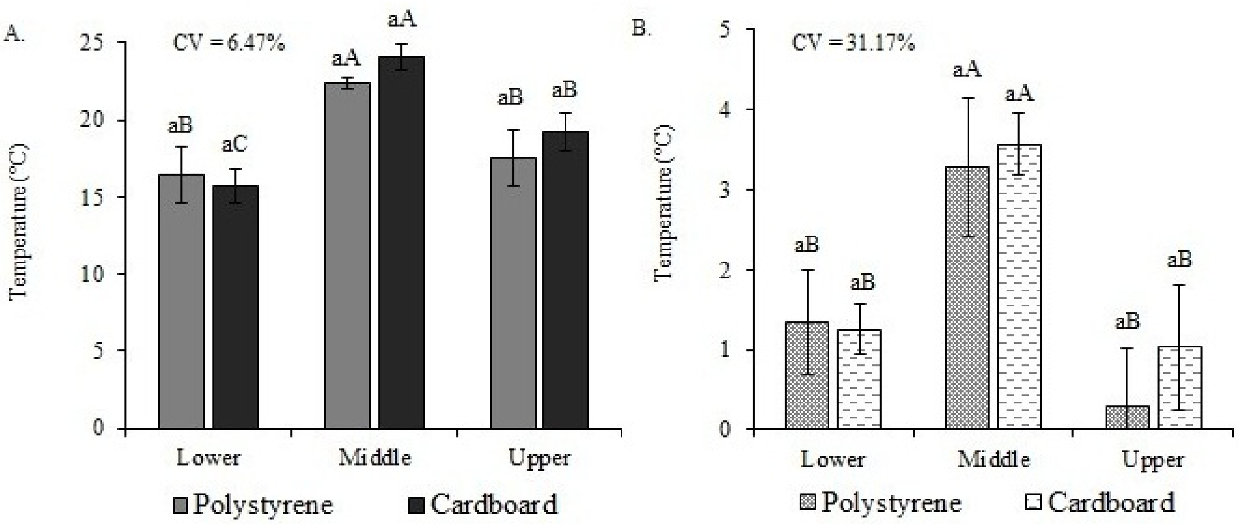
The analysis of variance at the beginning of the cooling showed that there was no significant difference between the packages at any height. Further, the cooling effects at the lower and upper heights using the polystyrene packaging were similar, differing significantly from that at the medium height, which had the highest average temperature values. It was also observed that there were significant differences between the temperatures at the three heights in the pallet with cardboard boxes, and the medium level also showed the highest mean temperature values (Figure 4A).

At the end of cooling (Figure 4B), the same situation was observed in relation to the packages (there was no difference between the temperatures in the packages at any of the heights). In both types of packages, the temperatures at the lower and upper heights did not differ; however, they were different from the middle level, which presented a higher average temperature. It was also observed that the temperature target (0 °C) was not reached at the end of the cooling time in either type of package.

However, this may be attributed not only to the low efficiency of the cooling room, but also to the types of packaging used. The percentage of openings in both the types of packages were not sufficient to favor adequate cold air circulation in the entire pallet, thus, limiting the heat exchange and cooling. Kader (2002) and Teruel (2008) recommend an effective opening area of 5 – 10 % to ensure efficient cooling under forced air conditions.

Indeed, it was verified in this study that the polystyrene and cardboard packages had effective opening areas of 4.88 and 1.72 %, respectively. Dussán-Sarria & Honório (2005) showed that the rate of heat transfer of figs depended on the package because it worked as a barrier to airflow, temperature variations, and change in the relative humidity of the cooling air, thus, preventing adequate heat transfer.

Prior to this study, the initial hypothesis was that table grapes placed in polystyrene packaging would take longer to cool because the material was more insulating than cardboard. However, it was observed that the opening area directly affected the cooling process. Therefore, the opening size was more influential than the type of packaging material. Several authors have shown that the effective opening area in packages directly influences the cooling speed (Talbot & Chau, 1991; Teruel et al., 2002).



Mean values followed by different uppercase or lowercase letters are statistically different between heights or packages in the pallets, respectively, according to Tukey's test at $p \leq 0.05$; CV – Coefficient of variation

Figure 4. Mean air temperature values inside two types of packages in the pallets at different heights at the beginning (A) and at the end (B) of forced air cooling

According to Teruel (2008), most vegetable packages used in Brazil have 3 to 7 % effective opening area, and only 50% of these are usable during cooling. In a study on the cooling behavior, quality, and shelf-life of products associated with package ventilation, Defraeye et al. (2015a) concluded that for each cold chain configuration, a specific package should be designed.

The other factors that might have been crucial in the cooling process were the amount and location of the openings in the clamshell containers used. For both types of boxes, similar clamshell containers were used, which had small holes located at the bottom and in the lid, with the sides completely closed. This made it a strong barrier for air flow and forced air cooling. According to Yuhui et al. (2020), apart from the box material, internal packaging such as bags and plastic coatings can also influence the efficiency of forced air cooling of products.

The ventilation area is a crucial factor in reducing the heterogeneity of the cooling. This must be large enough to allow efficient airflow through the packages and the entire pallet. However, in practice, there must be an ideal ventilation area to maintain the balance between the fast cooling of the products and the mechanical resistance of the packaging (Yuhui et al., 2020).

The forced cooling room was operated for 15.5 h (Figure 5). However, the recommendation, as described by Lima & Guerra (2018), is 8 to 14 h, which proves the inefficiency of the studied cooling system. According to Oliveira (2017), the time required to reduce the product temperature to the recommended values characterizes the cooling efficiency. The shorter this time, the more efficient the cooling, maintaining the quality of the product and increasing the shelf life.

The relative air humidity of air in the cooling room was below the recommended value of 90 – 95% (Ardente et al., 2015). In an environment with low relative air humidity, the water potential of the air is lower than that of the fruit tissue, causing the movement of water from the inside to the outside of the fruit. This results in fruit dehydration and weight loss, berry softening, and stem darkening (Mukama et al., 2018; Spagnol et al., 2018).

To increase the relative humidity of the air, it is necessary to introduce a larger amount of water into the environment. Many farms pour water on the ground; however, there is greater proliferation of fungi in the wooden body of the pallets, which can also reach the fruits. Therefore, a possible solution would be to install additional water injector nozzles in the cooling room.

According to the analysis of variance for the relative air humidity at the beginning of the forced air cooling (Figure 6A), it was noted that there was a significant difference between the humidity values of the packages at the lower height only. When

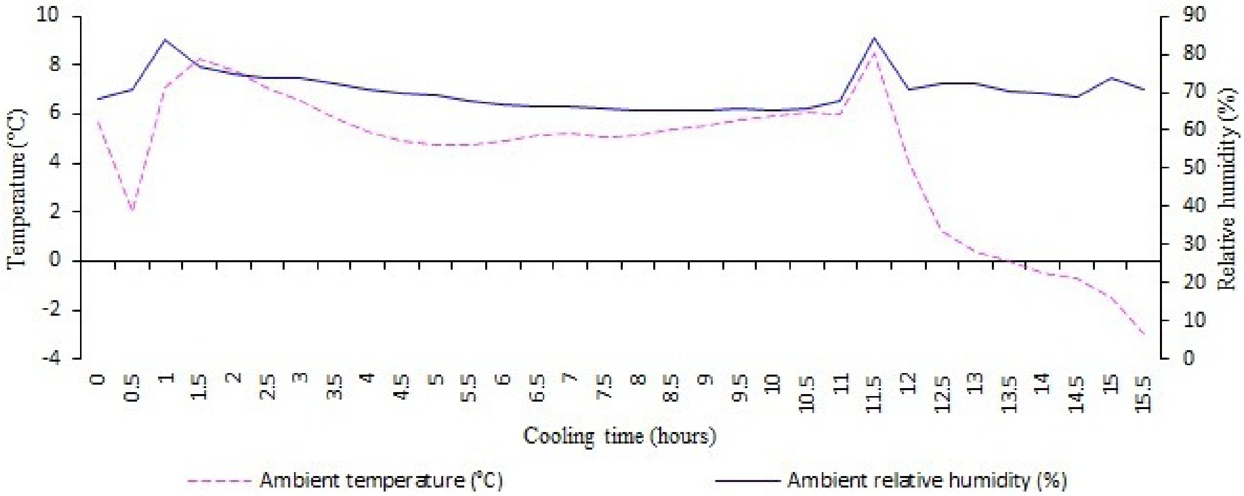
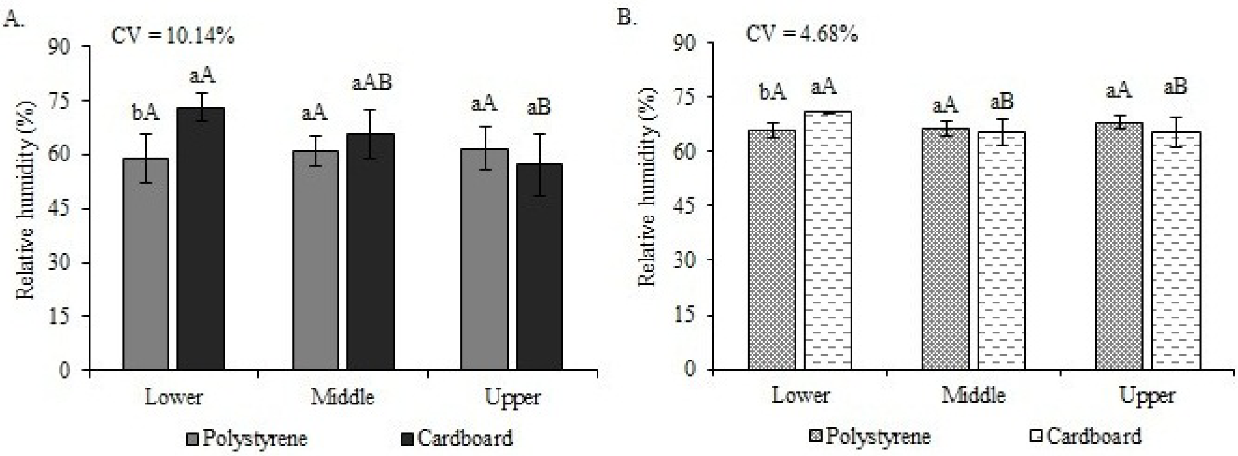


Figure 5. Ambient air temperature and relative air humidity during the period of operation of the forced air cooling room



Mean values followed by different uppercase or lowercase letters are statistically different between heights or packages in the pallets, according to Tukey's test at p ≤ 0.05; CV – Coefficient of variation

Figure 6. Mean relative air humidity values inside two types of packages in the pallets at different heights at the beginning (A) and at the end (B) of forced air cooling

evaluating the polystyrene package, there were no significant differences between the humidity values at the three heights, and the lower height presented the lowest mean moisture values. However, when evaluating the cardboard package, it was observed that the values at the lower and upper heights were statistically different. In addition, the medium level presented an interaction between the treatments. The lower height presented the highest relative air humidity, which was still below the recommended value.

At the end of the forced air cooling, there were also significant differences between the humidity values in the packages at the lower level (Figure 6B). In the polystyrene package, there were no significant differences between the values at the different heights, similar to that for temperature. In the pallet with cardboard boxes, the humidity values at the middle and upper levels were similar but different from the value at the lower height, which presented higher relative air humidity. However, this value was also below the recommended relative humidity value.

Conclusions

1. No difference in the cooling effect was observed between polystyrene and cardboard boxes, both of which showed unfavorable design for fast cooling.

2. Different cooling rates were achieved at different heights and at different positions of airflow within the pallet, with a temperature gradient of approximately 3 °C.

3. The central region of the pallet, both vertically and horizontally, presented a zone of heat concentration and was more resistant to cooling.

4. The cooling room showed low relative air humidity values (mean of 70.33%), which was not adequate for table grapes.

Acknowledgments

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Literature Cited

Ardente, F.; Pastor, M. C.; Mathiue, F.; Peiró, L. T. Analysis of end-of-life treatments of commercial refrigerating appliances: Bridging product and waste policies. Resources, Conservation and Recycling, v.101, p.42-52, 2015. https://doi.org/10.1016/j.resconrec.2015.05.005

Badia-Melis, R.; Mc Carthy, U.; Ruiz-Garcia, L.; Garcia-Hierro, J.; Villalba, J. R. New trends in cold chain monitoring applications – a review. Food Control, v.86, p.170-182, 2018. https://doi.org/10.1016/j.foodcont.2017.11.022

Baird, C. D.; Gaffney, J. J.; Talbot, M. T. Design criteria for efficient and cost effective forced-air cooling systems for fruits and vegetables. ASHRAE Transactions, v.94, p.1434-1453, 1998.

Berry, T. M.; Fadiji, T. S.; Defraeye, T.; Opara, U. L. The role of horticultural carton vent hole design on cooling efficiency and compression strength: A multiparameter approach. Postharvest Biological and Technology, v.124, p.62-74, 2017. https://doi.org/10.1016/j.postharvbio.2016.10.005

Bishnoi, R.; Aharwal, K. R. Experimental investigation of air flow field and cooling heterogeneity in a refrigerated room. Engineering Science and Technology, an International Journal, v.23, p.1434-1443, 2020. https://doi.org/10.1016/j.jestch.2020.05.004

Bovi, G. G.; Rux, G.; Caleb, O. J.; Herppich, W. B.; Linke, M.; Rauh, C. Medição e modelagem de perdas de transpiração em morangos embalados e não embalados. Biosystems Engineering, v.174, p.1-9, 2018. https://doi.org/10.1016/j.biosystemseng.2018.06.012

Defraeye, T.; Cronjé, P.; Verboven, P.; Opara, U. L.; Nicolai, B. M. Exploring ambient loading of citrus fruit into reefer containers for cooling during marine transport using computational fluid dynamics. Postharvest Biological and Technology, v.108, p.91-101, 2015a. https://doi.org/10.1016/j.postharvbio.2015.06.004

Defraeye, T.; Verboven, P.; Opara, U. L.; Nicolai, B.; Cronjé, P. Feasibility of ambient loading of citrus fruit into refrigerated containers for cooling during marine transport. Biosystems Engineering, v.134, p.20-30, 2015b. https://doi.org/10.1016/j.biosystemseng.2015.03.012

Delele, M. A.; Ngcobo, M.; Getahun, S.; Chen, L.; Mellmann, J.; Opara, U. Studying airflow and heat transfer characteristics of a horticultural produce packaging system using a 3-D CFD model. Part I: model development and validation. Journal of Food Engineering, v.86, p.536-545, 2013. https://doi.org/10.1016/j.postharvbio.2013.08.014

Dussán-Sarria, S. S.; Honório, S. L. Parâmetros de resfriamento rápido do figo (*Ficus carica* L.) cv. roxo de Valinhos embalado em caixa de exportação. Revista UDO Agrícola, v.5, p.96-102, 2005.

Elansari, A. M.; Fenton, D. L.; Callahan, C. W. Precooling. Postharvest Technology of Perishable Horticultural Commodities, p.161-207, 2019. https://doi.org/10.1016/B978-0-12-813276-0.00006-7

Goedhals-Gerber, L. L.; Khumalo, G. Identifying temperature breaks in the export cold chain of navel oranges: A Western Cape case. Food Control, v.110, 2020. https://doi.org/10.1016/j.foodcont.2019.107013

Inestroza-Lizardo, C.; Voigt, V.; Muniz, A.C.; Gomez-Gomez, H. Métodos de enfriamiento aplicables a frutas y hortalizas enteras y minimamente procesadas. Revista Iberoamericana de Tecnología Postcosecha, v.17, p.149-161, 2016.

Kader, A. A. Postharvest technology of horticultural crops. 3.ed. Davis: Division of Agriculture and Natural Resources, University of California, 2002. 295p.

Laguerre, O.; Hoang, H.; Flick, D. Experimental investigation and modelling in the food cold chain: Thermal and quality evolution. Trends in Food Science & Technology, v.29, p.87-97, 2013. https://doi.org/10.1016/j.tifs.2012.08.001

Lima, M. A. C. de; Guerra, C. C. Uva: Do plantio à colheita. Viçosa: Editora UFV, 2018. p.163-185.

Mataragas, M.; Drosinos, E. H.; Tsola, E.; Zoiopoulos, P. E. Integrating statistical process control to monitor and improve carcasses quality in a poultry slaughterhouse implementing a HACCP system. Food Control, v.28, p.205-211, 2012. https://doi.org/10.1016/j.foodcont.2012.05.032

Mukama, M.; Ambaw, A.; Berry, T. M.; Opara, U. L. Analysing the dynamics of quality loss during precooling and ambient storage of pomegranate fruit. Journal of Food Engineering, v.245, p.166-173, 2018. https://doi.org/10.1016/j.jfoodeng.2018.10.020

Oliveira, J. R. de. Comparação dos processos de pré-resfriamento e armazenagem para a manutenção da qualidade da maçã fuji. Florianópolis: UFSC, 2017. 285p. Tese Doutorado

Spagnol, W. A.; Silveira Junior, V.; Pereira, E.; Guimarães Filho, N. Reducing losses in the fruit and vegetable chains by the analysis of shelf life dynamics. Brazilian Jounal of Food Technology, v.21, p.1-10, 2018. https://doi.org/10.1590/1981-6723.6916

Talbot, M. T.; Chau, K. V. Precooling strawberries. Gainseville: Institute of Food and Agricultural Sciences, University of Florida. 1991. 11p. Circular 942

Teruel, B. M. Tecnologias de resfriamento de frutas e hortaliças. Revista Brasileira Agrociência, v.14, p.99-220, 2008.

Teruel, B. M.; Cortez, L. A.; Leal, P. M.; Lima, A. G. Estudo teórico do resfriamento com ar forçado de frutas de geometrias diferentes. Revista Ciência e Tecnologia de Alimentos, v.21, p.228-235, 2001. https://doi.org/10.1590/S0101-20612001000200019

Teruel, B. M.; Cortez, L. A.; Leal, P. M.; Neves Filho, L. C. Resfriamento de banana-prata ar forçado. Revista Brasileira de Fruticultura, v.24, p.142-146, 2002. https://doi.org/10.1590/S0100-29452002000100031

Todd, E. C. Foodborne disease and food control in the Gulf States Food Control, v.73, p.341-366, 2017. https://doi.org/10.1016/j.foodcont.2016.08.024

Wu, W.; Defraeye, T. Identifying heterogeneities in cooling and quality evolution for a pallet of packed fresh fruit by using virtual cold chains. Applied Thermal Engineering, v.133, p.407-417, 2018. https://doi.org/10.1016/j.applthermaleng.2017.11.049

Wu, W.; Haller, P.; Cronjé, P.; Defraeye, T. Full-scale experiments in forced-air precoolers for citrus fruit: impact of packaging type and fruit size on cooling rate and heterogeneity. Biosystems Engineering, v.169, p.115-125, 2018. https://doi.org/10.1016/j.biosystemseng.2018.02.003

Yuhui, C.; Ya-Fang, G.; Xin-Rong, Z. Impact of ventilation design on the precooling effectiveness of horticultural produce - A review. Food Quality and Safety, v.4, p.29-40, 2020. https://doi.org/10.1093/fqsafe/fyaa004