Effect of fan speeds on some horticultural produces characteristics under forced-air cooling

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Abstract: Forced-air cooling in conjunction with ice can rapidly remove field heat of fresh horticultural produce, and enhance their preservation. In the current work, a forced-air cooling technique was developed using standard method, and the effect of the fan speeds (31, 35, and 45ms^{-1}) on the cooling time, sensory properties and microstructure of three different cooled products (okra, tomato, and green bell pepper) were investigated using standard methods. The results within the experimental conditions showed that the forced-air cooling technique lowers the temperature faster, and significantly reduces the cooling time ($p \leq 0.05$) of all the products when compared with the time of cooling under room cooling condition. The time of cooling the tomato from ambient (32^{o}C) to half-cooled is 5, 6, and 8 minutes when the product is cooled using fan speeds of 31, 35, and 45 ms^{-1}, respectively. The sensory experiences evoked by various food panelists delivered pleasure in the final quality of the cooled products. In addition, the microstructures of the cooled samples were well-preserved when the machine was operated under the fan speed of 31m s^{-1}. However, the results presented in this work show that forced-air cooling technique plays a significant role to postharvest preservation of horticultural produce.

Keywords: Forced-air cooling,horticultural produce,fan speeds, microstructure, preservation

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1 Introduction

Fresh horticultural produce like okra, tomato and green bell pepper contain health-promoting compounds such as vitamins, carotenoids and phenolic compounds (Alabi et al., 2022;Elhadi et al., 2019; Manchali et al., 2012). However, fresh horticultural produce deteriorate very fast after harvest, and cause continuous loss of quality along the supply chain, putting upward pressure on food security worldwide(Ferreira et al., 2018; Gleice et al., 2019; Porat et al., 2018; Wang et al., 2021; Yan et al., 2018; Zhu et al., 2019). The challenges of food insecurity have increased the importance of addressing the quality loss of harvested horticultural produce. The quality loss is often cause by the presence of field heat and metabolic activities that occur from respiration (oxidation of sugars to produce carbon dioxide, water and heat) processes (Alabi et al., 2021; Gleice et al., 2019; Porat et al., 2018; Ribeiro et al., 2018; Sibanda and Seyoum, 2021; Souzan et al., 2018). Therefore, product's postharvest quality is influenced by its respiratory activity. By cooling or lowering temperature, respiration is reduced and senescence is delayed, thus preserving quality of horticultural produce(Carlos et al., 2018; Duan et al., 2020; Ferreira et al., 2018; Gleice et al., 2019; Sibanda and Seyoum, 2021; Yan et al., 2018). Forced-air

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cooling technique is one of the most common methods applied for preservation of fresh horticultural produce. The technique provides an air movement between produce surface and its adjacent sides (Gopala, 2015; Han et al., 2017). During operation, forced-air interferes within the produce being cooled, leading to a much faster cooling rate, high energy conservation, and management when compared with the conventional room cooling system (Han et al., 2017; Zhao et al., 2016). With this advantage, forced-air cooling has been demonstrated to preserve peach (Ferreira et al., 2018), and other main fresh produce (Alabi et al., 2021; Ferreira et al., 2018; Zhao et al., 2016). Rab et al.(2013) reported that air cooling of tomato resulted in significant higher fruit firmness and ascorbic acid content as compared to the samples cooled under conventional cooling method. In another study, forced-air cooling induced an increase of antioxidant activity of activity of apricots (Yan et al., 2018).

One limitation of forced-air cooling is that, if the fans speeds are not high enough, or are not uniformly distributed within the cooling chamber, this can cause chilling injury (Han et al., 2018; Salamat et al., 2020), and affect sensory properties, thereby reducing market value. More so, the air cooling technologies available are costly and complex in design. However, the efficiency of a forced-air cooling technology can be increased by better air management. Fans, in conjunction with a refrigeration system (ice) are normally used to cool the air passing through the product(Nalbandi et al., 2016; Yan et al., 2018). Hence, there is a need to develop an affordable forced-air- ice cooling technology that can be applied to maintain the quality and safety of horticultural produce. Therefore, the objective of this work was to develop a forced-air ice cooling technology and determine the effect of fan speed on cooling rate and qualities of okra, tomato and green bell pepper.

2 Material and methods

The fresh horticultural produce including okra (Abelmoschus esculentus), tomato (Solanum lycopersicum), and green bell pepper (Capsicum annum) were harvested from the field at Kwara State University Malete (KWASU), Nigeria (51^o 27$'$ 49.144$''$ N 19^o 13$'$ 4.303" E) in the morning between 9 and 11 am, May 2021. The harvested produce and the developed forced-air ice cooling technology, based on the procedure given by Adedamola(2021), are shown in the appendix. The produce was cooled immediately using the developed forced-air ice cooling technology at the Laboratory, Department of Food and Agricultural Engineering, KWASU. The constructed forced-air cooling chamber (36 cm height, 35 cm wide × 40 cm length box) was incorporated with ice and lag with jute sack to protect it from cooling loss. The relative humidity inside the box was 85% – 90%. A digital tachometer (DT2234$^+$ USA) was used to measure the fan speeds. The tachometer was pointed at the rotating fan (Kamisafe, 4 inch/5cm blades, 3.7 V, shaft radius of 0.25 m) blades that have a continuous working time of 8 hours at least. The tachometer measured the reading of 'blades per minute' within few seconds. The number displayed was then divided by the number of blades to obtain the fan speeds: and the speeds were as follows:

Low speed = 31 ms^{-1}

Medium = 35m s^{-1}

High speed = 45m s^{-1}

The harvested products were subjected to the following treatments: (1) forced-air cooling at 31m s^{-1} fan speed followed by cold storage at 4^{o}C; (2) forced-air cooling at 35m s^{-1} fan speed followed by cold storage at 4^{o}C; (3) forced-air cooling at 45m s^{-1} fan speed followed by cold storage at 4^{o}C and (4) control without forced-air cooling followed by cold storage at 4^{o}C.The temperature of the samples was measured at every 1 minute using a digital thermometer, and the procedure was repeated until the temperature reached the store temperature of 4^{o}C±1^{o}C. The temperatures of the harvested products before initiating the forced-air cooling treatment were between 30^{o}C to 32^{o}C. At the end of cooling process, the vegetables were removed from the cooling chamber and were put into cold store at 4^{o}C for 24hrs.

2.1 Cooling rate

The cooling rate was calculated by dividing each temperature data point by its corresponding time point, according to Kumar et al. (2008) as given in Equation 1 below:

$$Cooling\ rate\ (℃/sec) = \frac{\Delta T}{\Delta t} \quad (1)$$

where, $\Delta T$is the change in temperature (^{o}C) and $\Delta t$is the change in time (sec).

2.2 Sensory analysis

The forced-air cooled produce was assessed for appearance, texture, mouth feel, cohesiveness of mass, moistness and overall acceptability using a 9-point hedonic scale test (1 = extremely dislike, 9 = extremely like) and compared with samples cooled under conventional (control) room cooling. Nine trained panelists were selected based on their interest and product familiarity. As part of the training, the assessors cleansed their palates with distilled water before the mouth feel test and anytime during the test as prescribed byLim(2017).

2.3 Microstructure analysis

Scanning electron microscope (SEM) studies were performed on the surface of the produce subjected to forced-air ice cooling to determine the effectiveness of cooling on morphological changes on the final products. The samples cooled under conventional (control) room cooling were served as controls. The SEM method utilized in this study was based on methods of Kockro et al.(2000) with slight modifications. The forced-air ice cooled samples and control samples were analyzed to investigate whether or not forced-air ice cooling technique preserved the microstructures of the final products according to the fan speeds. Samples for SEM were prepared for each horticultural produce, and the specimens (approximately 4 mm^2) were cut and fixed with glutaraldehyde in 0.1 M sodium phosphate buffer (pH 7.2) for 24 hrs. Afterwards, the samples were dehydrated by sequential exposure to ethanol concentrations ranging from 30% to 100% in 10 minutes. After dehydration, samples were briefly rinsed with distilled water to remove any artifacts and then dried with CO_2 and mounted on aluminum stubs. Base on Kockro et al.(2000) procedure, the specimens were then coated with gold in an ion SEM sputter coater for 2 minutes, and examined with a Philips PSEM 500 scanning electron microscope.

2.4 Statistical analysis

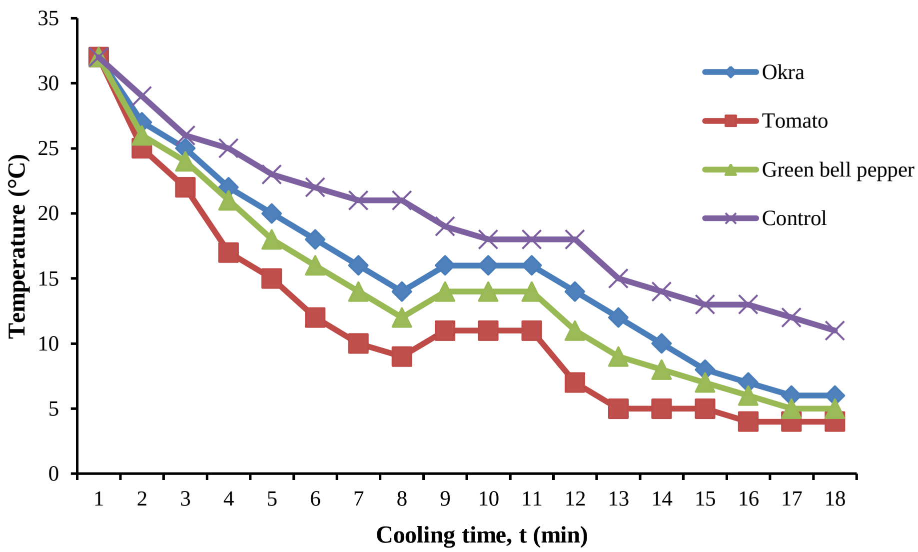
All measurements taken from the experiments were analyzed in terms of effect of fan speed on the cooling efficiency and quality of cooled okra, tomato and green pepper. The fan speeds were selected as fixed factors. The cooling efficiency and quality studied including cooling rate and sensory properties were regarded as response variables. One-way analysis of variance (ANOVA) was employed using SPSS (IBM 21) statistical tool, and the significance was set at the level of 0.5, considering the main effects to arrive at the best results of the treatments.

3 Results and discussion

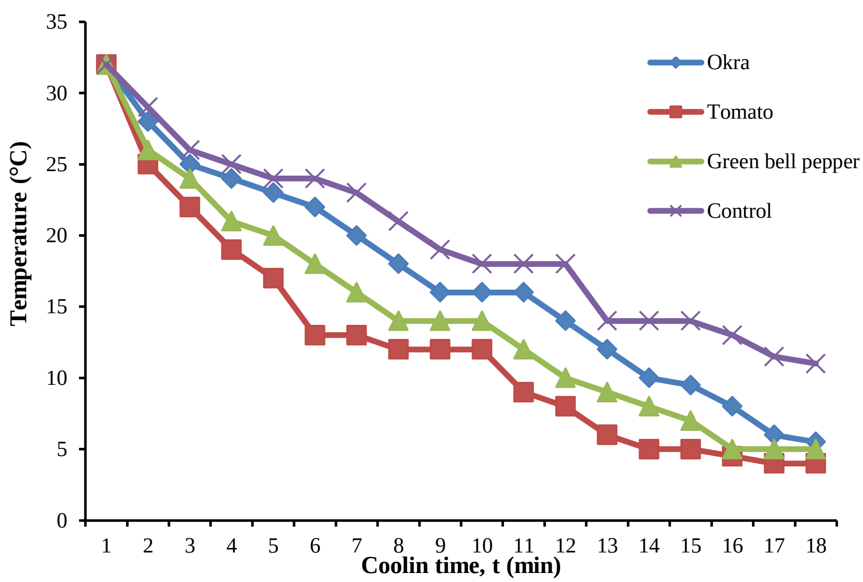
3.1 Cooling rate

The cooling rate of the samples cooled under conventional room are almost the same for the three products and slower than the samples cooled under forced-air ice cooling system. The forced-air ice cooling system is characterized with rapid temperature drop for all the products under study. Figure 1show the temperature evolution for the treated and untreated (control) samples during the forced-air ice cooling operated at fan speeds of 31, 35 and 45m s^{-1} respectively.

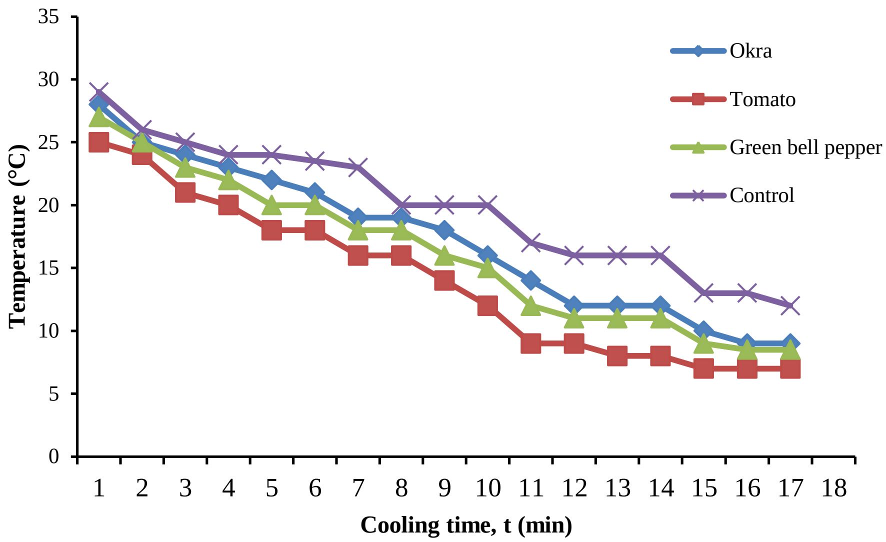
The results indicated that the temperature of tomato and green bell pepper dropped faster than the temperature of okra. The faster heat transfer observed on tomato and green bell pepper was attributed to the small surface areas of the products, which is in agreement with the finding of (Alabi et al., 2020), However, the temperatures drops in the samples were slightly different due to product properties (such as size, shape, pores distribution) and process parameters (i.e. fan speeds). For example, tomato showed a faster temperature dropped when the forced –air cooling system is operated at 31m s^{-1}, because lower fan speed produces more cooling effect (Gopala, 2015). Typically, small-sized products allow fast cooling, due to a short distance required for heat transfer through the sample mass when compared with big samples (Alabi et al., 2022; Alabi et al., 2020). Surprisingly, the temperatures of all samples treated under fan speeds 31 m s^{-1} and 35m s^{-1} were characterized with rapid temperature drop at the initial stage. But after few minutes, the treated samples have temperature (up to 1°C) rise for 3 minutes. This phenomenon demonstrated that the forced-air cooling system operated at 31 m s^{-1} and 35m s^{-1} allow heat transfer across the stomata, where the heat migration pattern weakened with increase in the product surface area, resulting in the rising stage and constant for few minutes before falling again as observed for all the samples.



(a) cooled at fan speed of 31 m s^{-1}

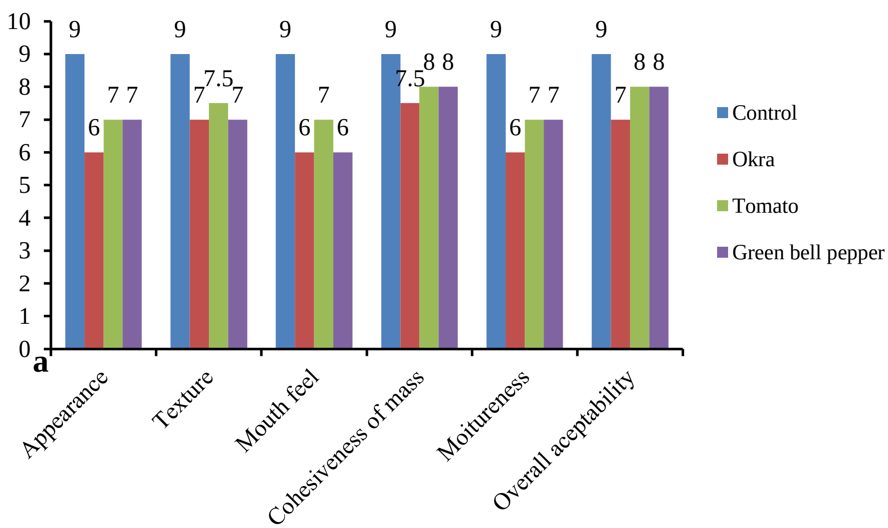


(b) cooled at fan speed of 35 m s^{-1}

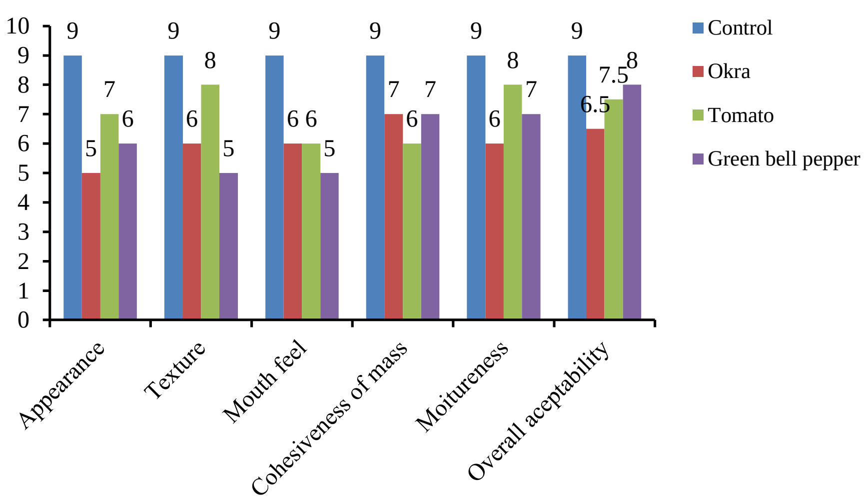


(c) cooled at fan speed of 45 m s^{-1}

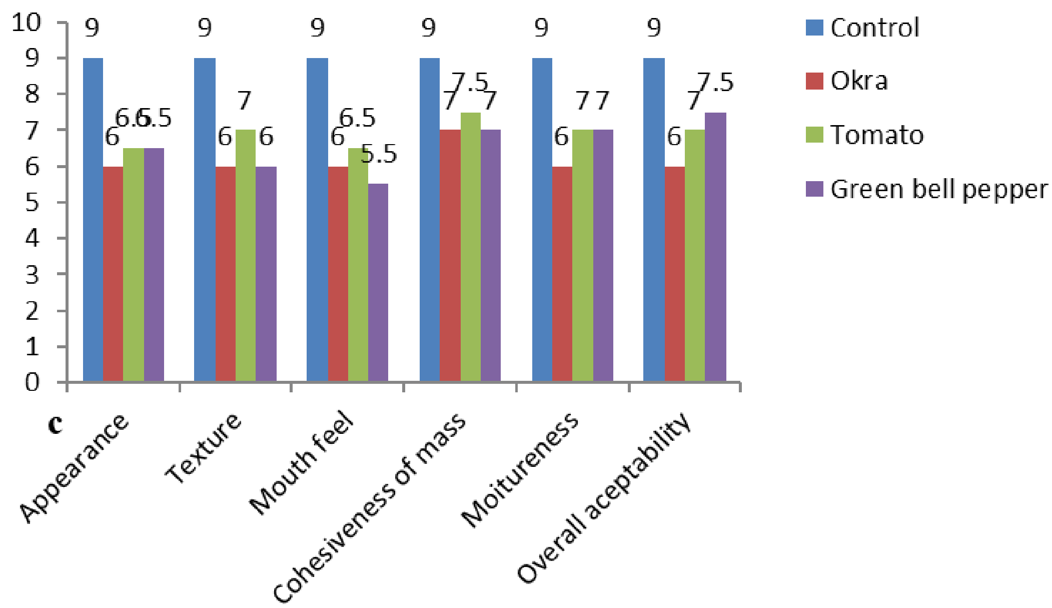
Figure 1Effect of forced-air ice cooling time on okra, tomato and green bell pepper temperature



(a) at 31 m s^{-1}



(b) 35 m s^{-1}



(c) 45 m s^{-1}

Figure 2 Effect of fan speeds on sensory parameters during forced-air ice cooling of okra, tomato and green bell pepper

Table 1Duncan multiple range test (DMRT) of the effect of fan speeds on sensory properties of forced-air ice cooled horticultural produce

Sample/ Treatment			Sensory properties: Appearance	Texture	Mouth feel	Cohesiveness of mass	Moistureness	Overall acceptability
	Control		9.00 ±07^{a}	9.00 ±00^{a}	9.00 ±00^{a}	9.00 ±00^{a}	9.00 ±00^{a}	9.00 ±00^{a}
Okra	Fan speed	31	6.00 ±07^{e}	7.00 ±07^{c}	6.00 ±07^{e}	7.50 ±07^{b}	6.00 ±07^{e}	7.00 ±07^{c}
		35	5.00 ±07^{d}	6.00 ±07^{e}	6.00 ±07^{e}	7.00 ±07^{c}	6.00 ±07^{e}	6.50 ±07^{d}
		45	6.00 ±07^{e}	6.00 ±07^{e}	6.00 ±07^{e}	7.00 ±07^{c}	6.00 ±07^{e}	6.00 ±07^{e}
Tomato	Fan speed	31	7.00 ±06^{d}	7.50 ±06^{c}	6.96 ±06^{d}	8.03 ±06^{b}	7.00 ±06^{d}	8.00 ±06^{b}
		35	7.03 ±06^{d}	8.00 ±06^{b}	6.00 ±06^{f}	6.00 ±06^{f}	8.00 ±06^{b}	7.50 ±06^{c}
		45	6.50 ±06^{e}	7.00 ±06^{d}	6.50 ±06^{e}	7.50 ±06^{c}	7.00 ±06^{d}	7.00 ±06^{d}
Green bell pepper	Fan speed	31	7.00 ±14^{c}	7.00 ±14^{c}	6.00 ±14^{e}	8.00 ±14^{b}	7.00 ±14^{c}	8.00 ±14^{b}
		35	6.00 ±14^{e}	5.03 ±14^{g}	4.86 ±14^{g}	7.00 ±14^{c}	7.00 ±14^{c}	8.00 ±14^{b}
		45	6.50 ±14^{d}	6.00 ±14^{e}	5.50 ±14^{f}	7.00 ±14^{c}	7.00 ±14^{c}	7.16 ±14^{c}

Note: *Samples with the same superscript are not significantly different

Moreover, the forced-air ice cooling system lowers the temperature of the products and significantly reduces the cooling time ($p \leq 0.05$). The time of cooling the tomato from ambient (32^{o}C) to half-cooled is 5, 6, and 8 minutes when product is cooled using fan speeds of 31, 35, and 45m s^{-1}, respectively, as compared with the time (13 minutes) used for cooling the control samples under conventional room cooling condition. The effect of fan speeds on cooling time varies among the samples. At the fan speed of 35m s^{-1}, the temperature dropped for tomato, green bell pepper and okra were 9^{o}C, 11^{o}C, and 12^{o}C respectively, within the first 10 minutes. Whereas, it dropped to 8^{o}C, 10^{o}C, 11^{o}C when the machine was operated at a fan speed of 31m s^{-1}. The results indicate that the lower the fan speed, the faster the cooling rate and vice-versa.

3.2 Sensory properties

Figure 2 presents the results of the effect of fan speeds on the sensory parameters includingappearance, texture, mouth feel, cohesiveness of mass, moistness and overall acceptability.

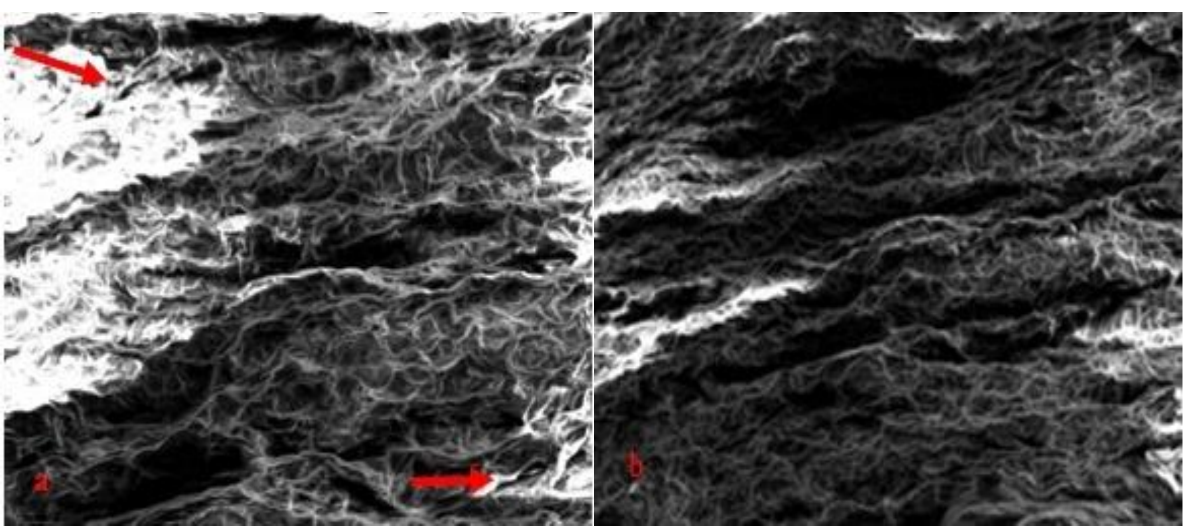
However, it can be observed that the forced-air ice cooling technique operated at fan speed of 31m s^{-1} offers most acceptable sensory properties. However, cooled tomato and green bell pepper had the highest cohesiveness of mass because of pores sizes and cell membrane permeability that allows low speed air to penetrate through the tissue substrate, resulting to molecular attraction and high resistance to shear force (Aked, 2002).

Table 1 show Duncan multiple range test (DMRT) of the effect of fan speeds on sensory properties of the forced-air ice cooled horticultural produce. Following the DMRT, the panelists indicated their preference for the three products cooled under each fan speed anchored 'dislike extremely' to like extremely'. The panelists expressed significant higher (p< 0.05) acceptance for green bell (7.5 – 8) over tomato (7-8) and okra (6-7). The results show that the sensory science is cognitively similar among the products, and that biological variability associated with allotting sensory judgment to the three similar products resulted in the significant differences of the sample at different fan speeds. However, the study indentifies qualities such as appearance, texture and moistureness as most likely key to acceptability of the produce after the cooling process.

3.4 Microstructure observation

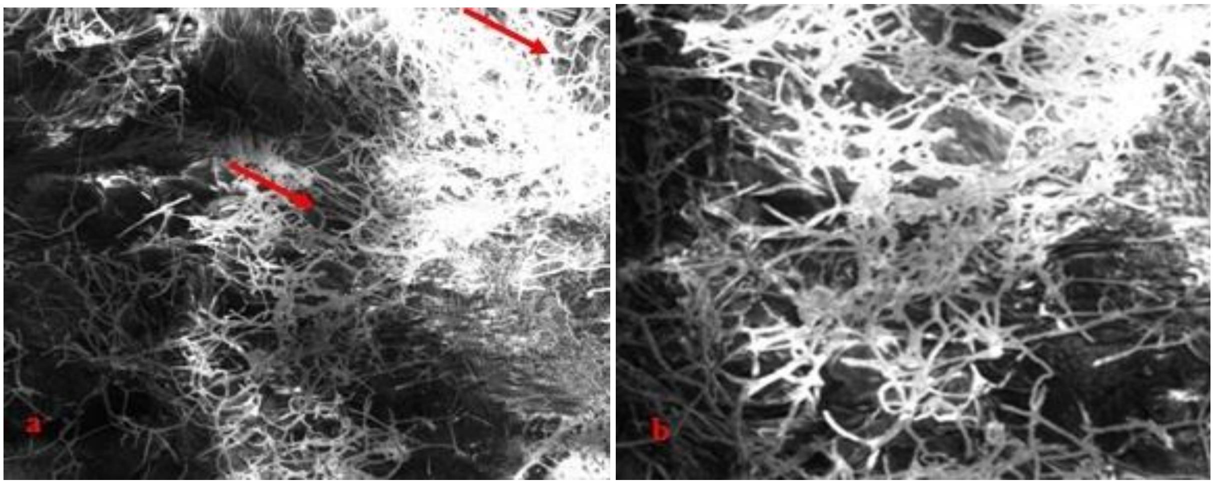
The microstructure changes, according to the best fan speed (at 31m s^{-1}) of the three horticultural products, are shown in Figures 3-5 for okra, tomato and green bell, respectively, as compared with the control sample. The microscopic analysis showedminimum damage to the cells because of the rapid evolution of heat in the cooled matrix being observed for samples cooled using the forced-air ice cooling technology. With rigid tissue, and higher permeability to air within the cellular tissue, there was a large opening of tomato and green bell pepper stomata, which drove the rapid transfer of heat out of the samples and cause minimal cell damage. The microstructures of the cooled products are related to their cell wall polymers, in which structural integrity of each produce is attributed to the primary cell wall, the middle lamella and turgor generated within cells by air diffusion (Terefe and Versteeg, 2011).

However, the results by Zhu et al.(2020) further confirmed the above tolerances, suggesting that there exit variation in membrane stability and microstructures of leaves due to their sensitivity to external treatment.



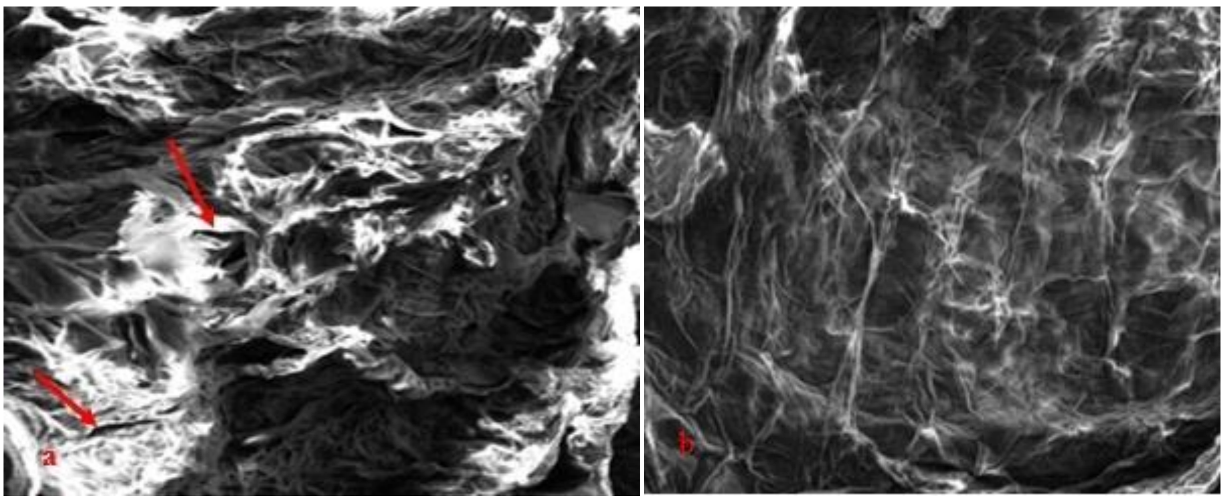
(a) microstructure of cooled okra after conventional room cooling (b) microstructure of okra after forced-air cooling (at 31 m s^{-1})

Figure 3Effect of forced-air ice cooling on microstructure of okra (Scale bar = 500 μm)



(a) microstructure of cooled tomato after conventional room cooling (b) microstructure of tomato after forced-air cooling (at 31 m s^{-1})

Figure 4Effect of forced-air ice cooling on microstructure of tomato (Scale bar = 500 μm)



(a) microstructure of cooled green bell pepper after conventional room cooling (b) microstructure of green bell pepper after forced-air cooling (at 31 m s^{-1})

Figure 5Effect of forced-air ice cooling on microstructure of green bell pepper (Scale bar = 500 μm)

4 Conclusion

Forced-air-ice cooling technique was applied to cool three different horticultural produces. The effect of fan speeds (31, 35, 45m s^{-1}) on the cooling rate, sensory properties and microstructure of okra, tomato, and green bell pepper were evaluated and compared with the cooled sample under conventional room cooling system. The results showed that forced-air ice cooling system reduced the air temperature inside the cooling chamber to $4^oC\pm1^oC$ from about 32^oC ambient temperature. More so, by operating the developed forced-air cooling system at a speed of 31m s^{-1}, 8, 9, and 10 minutes were required to reduce the temperature of okra, tomato, and green bell pepper to about $4^oC\pm1^oC$, $5^oC\pm1^oC$ and $6^oC\pm1^oC$ respectively. The fan speeds and variations in the product composition had significant effect on the cooling time, sensory properties and microstructures. However, despite the small temperature variations among the fan speeds, small-scale farmers can still use the forced-air ice cooling system to remove field heat from harvested horticultural produce.

Furthermore, the results indicate that the forced-air ice cooling technology could improve cooling rate, sensory properties and microstructures of the horticultural produces, when compare to conventional cooling, while fan speed of 31m s^{-1} could greatly improve the overall cooling performance.

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Author contributions

KPA conceptualized, performed the experiments and wrote the manuscript; AF edited the manuscript; MUA conducted data analysis.

References

Adedamola, M.U. 2021. Development of a low cost forced-air cooling device for some horticultural produces. B.Eng thesis, Department of Food and Agricultural Engineering, Kwara State University Malete, Ilorin, Nigeria.

Aked, J. 2002. Maintaining the post-harvest quality of fruits and vegetables. *Fruit and Vegetable Processing*, 4(2): 119–149.

Alabi, K.P., P. O.Ayoola,M. O. Adesoji, F. Adeshina,and L. O. Gabriel. 2022. Effects of osmotic dehydration pretreatment on freezing characteristics and quality of frozen fruits and vegetables. *Journal of Food Process Engineering*, 45(8): 1–13.

Alabi, K. P.,R. A. Oladipupo, F. T. Obateru, and A. Musbaudeen. 2021. Novel pre-cooling techniques and their effect on the quality of cooled fruits and vegetables.*Journal of Agricultural Engineering and Technology (JAET)*, 26(1): 88–103.

Alabi, K. P., Z. Zhu, and Sun, D. 2020. Transport phenomena and their effect on microstructure of frozen fruits and vegetables. *Trends in Food Science and Technology*, 101(3): 63–72.

Carlos, J., C.Santana, S. A. Araújo,W. A. L. Alves, and P. A. Belan. 2018. Optimization of vacuum cooling treatment of postharvest broccoli using response surface methodology combined with genetic algorithm technique. *Computers and Electronics in Agriculture*, 144(September): 209–215.

Duan, Y., G. Wang, O. A. Fawole, P. Verboven,X.Zhang,D.Wu, U. Linus,B. Nicolai, and K. Chen. 2020. Postharvest precooling of fruit and vegetables: A review. *Trends in Food Science and Technology*, 100: 278–291.

Elhadi, M. Y., G. S. Pablo, and E.M. Maria. 2019. Contribution of fruits and vegetables to human nutrition and health.*In Postharvest Physiology and Biochemistry of Fruits and Vegetables*, ed E. Yahia, and A. Carrillo-Lopez, 19–43. United Kingdom: Woodhead Publishing.

Ferreira, J., P.D.Silva, L.C.Pires, P.D.Gaspar,and J. Nunes 2018. Efficient cooling at post-harvest phase: a comparative study between air- cooling and hydro-cooling processes. In *AGRO 2018 − International Congress on Organizational Management, Energy Efficiency and Occupational Health and Safety in Agrifood Industry*, 1–8.CEi, Castelo Branco, Portugal, 3-4October.

Gleice,S.M. E.,S.A.Basílio, M.D. Milan, N. Arruda,and S. K. Benett 2019. Hydrocooling efficiency on postharvest conservation and quality of arugula. *Revista de Agricultura Neotropical*, 6(4): 36–41.

Gopala, R. C. 2015.Forced-air cooling of fruits and vegetables.In *Engineering for Storage of Fruits and Vegetables*, 1st eds. 10-24. United states:Academic Press.

Han, J., R.Badía-melis, X.Yang, L.Ruiz-garcia, J.Qian,and C. Zhao.2017.Cfd simulation of airflow and heat transfer during forced-air precooling of apples. *Journal of Food Process Engineering*, 40(2): 1–11.

Han,W., J.Zhao, P.Qian, L. Ruiz-Garcia,and X. Zhang. 2018. Numerical modeling of forced-air cooling of palletized apple: Integral evaluation of cooling efficiency. *International Journal of Refrigeration*, 89:131–141.

Kockro,R.A., J.A. Hampl, B. Jansen, G. Peters, M. Scheihing, R. Giacomelli, S. Kunze, and A. Aschoff. 2000. Use of scanning electron microscopy to investigate the prophylactic efficacy of rifampin-impregnated CSF shunt catheters. *Journal of Medical Microbiology*, 49(5): 441–450.

Kumar, R., A. Kumar, and U.N. Murphy. 2008. Heat transfer during forced air precooling of perishable products. *Biosystems Engineering*, 99(2): 228-233

Lim, J. 2017. Hedonic scaling: A review of methods and theory. *Food Quality and Preference*, 22(8): 733–747.

Manchali, S., M.K.N. Chidambara, and B.S. Patil. 2012. Crucial facts about health benefits of popular cruciferous vegetables. *Journal of Functional Foods*, 4(1):97–106.

Nalbandi, H., S. Seiiedlou, H. R. Ghasemzadeh, and F. Rangbar 2016. Innovative parallel airflow system for forced-air cooling of strawberries. *Food and Bioproducts Processing*, 100(partA):440–449.

Porat, R., A. Lichter,L.A. Terry, R. Harker, and J. Buzby. 2018. Postharvest losses of fruit and vegetables during retail and in consumers' homes: Quantifications, causes, and means of prevention. *Postharvest Biology and Technology*,139:135–149.

Rab, A., K. Nawab, and K. Ali. 2013. Harvest stages and pre-cooling influence the quality and storage life of tomato fruit. *Journal of Animal and Plant Sciences*, 23(5): 1347–1352.

Ribeiro, W. S., P.R. Cecon, and F.L. Finger. 2018. Shelf life of iceberg lettuce affected by hydro cooling and temperature of storage. *Advances in Horticultural Science*, 32(3): 319–324.

Salamat, R., H.R. Ghassemzadeh, S.F. Ranjbar, J. Mellmann, and H. Behfar. 2020. Dominant physical mechanisms governing the forced-convective cooling process of white mushrooms (Agaricus bisporus). *Journal of Food Science and Technology*, 57(10): 3696–3707.

Sibanda, S., and W.T. Seyoum. 2021. The influence of indirect air-cooling combined with evaporative cooling on tomato fruit cooling time and temperature. *Journal of Agriculture and Crops*, 7(72):69–75.

Souzan, S. L., H.M. Ali, M.N. Kenawi, and O.I.A. Soltan. 2018. Mass transfer and microstructure during osmotic dehydrofreezing of dates (Pheonix dactylifera). *Minia Journal of Agricultural Research and Development*, 23(6): 382–400.

Terefe, N. S., and C. Versteeg. 2011. Texture and microstructure of fruits and vegetables. In*Practical Food and Research*,ed. R. Cruz,4–56. NY: Nova Science Publishers.

Wang, J., T. Ma, L. Wang, T. Lan, Y. Fang, and X. Sun 2021. Research on the consumption trend, nutritional value, biological activity evaluation, and sensory properties of mini fruits and vegetables. *Foods*, 10(12): 356–360.

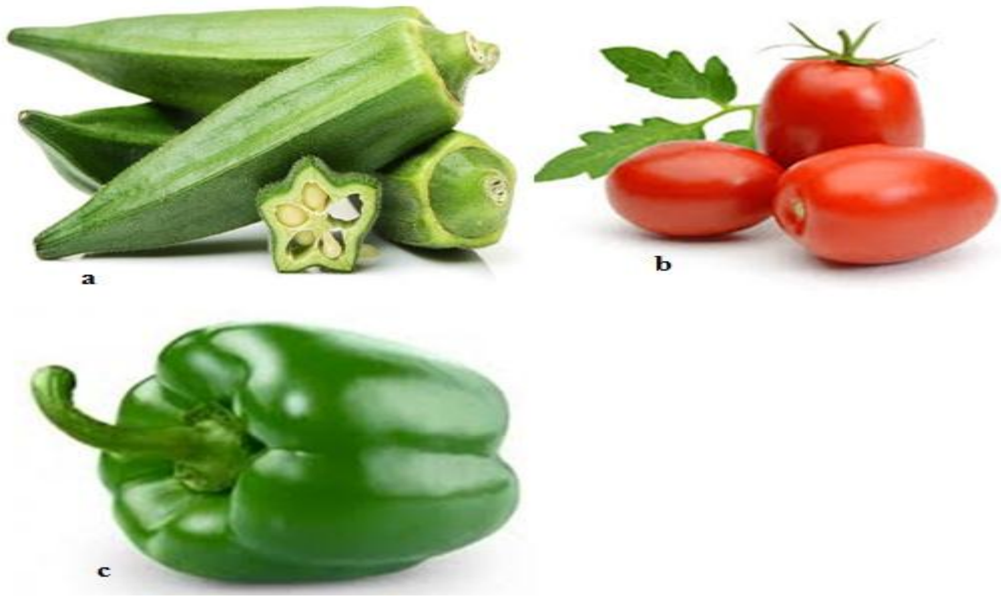
Yan, J., Y. Song, J. Li, and W. Jiang. 2018. Forced-air precooling treatment enhanced antioxidant capacities of apricots. *Journal of Food Processing and Preservation*,42(1): 1–7.

Zhao, J., W. Han, T. Yang, P. Qian, and L. Fan. 2016. A review of computational fluid dynamics for forced-air cooling process. *Applied Energy*, 168:314–331.

Zhu, Z., Y. Geng, and D. Sun. 2019. Effects of operation processes and conditions on enhancing performances of vacuum cooling of foods: A review. *Trends in Food Science and Technology*, 85:67–77.

Zhu, Z., Y. Geng, and D. Sun. 2020. Effects of pressure reduction modes on vacuum cooling efficiency and quality related attributes of different parts of pakchoi (Brassica Chinensis L.).*Postharvest Biology and Technology*,173(6):111409.

Appendix



(a) Okra (b) Tomato (c) Green bell pepper

Figure 6 Fresh vegetables

Figure 7 The 3D view of the cooling chamber