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Preservation and storage of fresh foods by pre-cooling

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Abstract
The high demand for fresh perishable food products and the need to preserve them has led to an increase in the need for pre-cooling. pre-cooling is the first step in cooling after harvesting, slaughtering, picking, and before storage and transportation to markets, in which the food products are cooled to low temperatures to remove the field or slaughter heat in this study, we experimentally analyse heat transfer during pre-cooling, which is conducted in a rectangular channel where air is recycled through a secondary channel connected to the primary one. Different food products, such as cantaloupe, red cabbage, and eggplant, are studied during the cooling process. the food products are placed in a dedicated place called a food package inside the rectangular air channel (length = 2 m, width = 0.3 m, and height = 0.3 m) connected to a smaller secondary channel used for air recycling, which is made of polyurethane material coated with a layer of aluminium with a thickness of (25-200) micrometres. The test results were calculated at ambient temperature ranging from 25.8-29.5 and three air flow rates (1.8, 3.6, 4.8) to calculate their effect on the cooling process dual thermocouples were inserted halfway into the food products to measure their temperature. The effect of the air velocity on the temperature change of the food product was studied, and it was found that choosing the appropriate air velocity reduces the cooling time and thus saves energy based on temperature without dimension, it is possible to save 27.5% of the cooling time in cantaloupe and 26.7% in red cabbage when using the highest velocity, while in eggplant, the lower air velocity is most appropriate for reducing dimensionless temperature and saving time and energy.

Keywords: Process, precooling, vegetables, fruits, preservation, refrigeration

1. Introduction

The methods and types of pre-cooling are important and vital topics in the fields of technology and engineering. The objective of this process is to reduce the temperature of materials before their use or storage, in order to achieve numerous benefits and the main goal of slowing down combustion reactions and delaying the degradation of material quality. The benefits of pre-cooling are numerous, as it contributes to freezing food materials that require long-term storage and enhances the ability of materials to retain their flavour, texture, and important nutrients. In addition, pre-cooling contributes to maintaining the safety and quality of sensitive industrial products and chemicals that require storage at low temperatures. However, one should also take into consideration the potential harm of the pre-cooling process. Although it has a positive impact on quality and safety, it should not be misused or materials should not be kept at low temperatures for a long time, as this can affect the physical and chemical characteristics of food, leading to the deterioration and loss of flavour, texture, and nutritional value. The use of pre-cooling methods and types in a proper and balanced manner can play a significant role in preserving the quality and safety of materials and contribute to enhancing the lifespan of different industries and products. It is also important not to exceed the use of this technology and to ensure the availability of appropriate equipment and necessary specifications to achieve the desired results [1]. The importance of pre-cooling agricultural products before sale in the market in order to preserve them from corruption and spoilage. There are several different pre-cooling techniques used in the agricultural sector, including air cooling and water and ice cooling techniques. These techniques are not effective equally due to the presence of hot spots in the products. However, water cooling may be the most suitable for products that need to be washed before sale in the market [2]. The pre-cooling technique is the most suitable for preserving the quality, flavour, and appearance of vegetables and fruits, as it controls the biological processes and chemical reactions that occur in them.

Improving pre-cooling techniques can contribute to reducing agricultural waste and providing more stored agricultural products [3]. Pre-cooling plays a role in increasing the efficiency of heat pumps in refrigeration systems. The hybrid cycle that uses an ammonia-carbon dioxide absorption heat pump has two main advantages: the first is a decrease in the evaporation temperature for cooling due to pre-cooling, and the second is the hybrid cycle is working in higher efficiency of compared to traditional solid systems of pre-cooling [4]. Pre-cooling has an impact on the performance of electronic devices. The concept of pre-cooling and its role in reducing the temperature of electronic devices, increasing their performance, and extending their lifespan are discussed [5]. The pre-cooling technique is important in ensuring food security and preserving the quality of food products whereas Pre-cooling constricted in preventing the growth of harmful microorganisms and food deterioration [6]. Food shortage is a major problem in many regions around the world, and yet one-third of total food production is disposed of as lost and wasted. This is related to approximately one-quarter of the land, water, and fertilizers used in crop production [7]. waste and loss in food and the harmful impact it has on social, economic, and environmental levels. Research indicates that about one third of food manufactured for human consumption, or nearly 1.3 billion tons annually, is wasted or lost. Shedding light on appropriate methods for food preservation to reduce waste and loss, these methods include pre-cooling and proper preservation techniques. Developing countries especially need to improve storage conditions and infrastructure. The study indicates that approximately 10% of crops are lost in the field in developed countries. The food loss problem in India is addressed by wasting 21 million tons of wheat annually due to inadequate storage and distribution system [8]. It is necessary to implement preventive measures to minimize food spoilage, including the use of chemical treatment or pre-cooling which consider One of the effective ways to maintain food quality, although it may not be the cheapest method for each type of food, is the consideration of equipment, energy, and time costs [9]. Thermal and mass analysis study for cold food preservation shows that increasing the time required for pre-cooling leads to improved product quality, reduced weight loss, and delayed spoilage. Additionally, temperature and relative humidity significantly impact the effectiveness of pre-cooling [10]. Studying the variation of humidity in the air and its effect on the cooling process. Humidity distribution has a significant influence on the behaviour of the cooling process, and understanding this process well can help improve cooling efficiency and results [11]. Pre-cooling using compressed air has proven its effectiveness in improving food quality and extending its shelf life. It is important to study the effects of these methods on consumer health and determine the optimal limits for their application [12]. Improving the pre-cooling process requires increasing air flow rate and raising the desired final temperature, contributing to equipment performance improvement and energy consumption reduction [13]. The use of pre-cooling in the food industry and its importance in maintaining product quality, extending shelf life, and preventing deterioration [14]. Pre-cooling is important in the frozen food industry and the use of the cryogenic cooling technique to minimize temperature changes and preserve the quality of frozen products. The cryogenic cooling technique is the most suitable for maintaining the quality of frozen products because it allows the management of the complex relationship between variable time and temperature in a constant volume system. This technique relies on the principles of minimum free energy and mass preservation, providing a relationship between product quality and varying product temperature over the two-phase stage of solid and liquid [15]. The importance of precooling in the bread industry and its impact on quality. Precooling is one of the effective methods to maintain the quality and improve the appearance, taste, and shelf life of bread, as well as to reduce weight loss. Cooling by Freezing is the best method as it preserves the quality and does not cause any changes in taste, while conventional cooling may affect the quality and taste [16]. Improvement of the current design of storage containers and the use of techniques such as computer modelling are necessary to enhance product quality and maintain thermal balance. The use of computational dynamics models to study air flow patterns and heat transfer within containers during precooling process is key. Focus is given to detailed and comprehensive mathematical modelling to simulate air flow, heat transfer, and mass transfer that occur during food cooling [17]. The use of information technology can improve decision-making and enhance managers' ability to improve the safety and security of grain storage and transportation [18]. The concept of precooling and its importance in improving energy generation efficiency and material production. The use of precooling can increase industrial process efficiency and reduce production costs [19]. Precooling is an effective strategy to increase energy consumption efficiency in food stores, preserve the environment, and reduce greenhouse gas emissions associated with these processes [20]. Precooling methods are essential in preserving the quality of food products during storage and distribution. The benefits of precooling include reducing weight loss, limiting bacterial and fungal growth, reducing energy requirements, and minimizing pollution. However, there are potential disadvantages such as increased production costs, variation in flavour and nutritional value, and being limited to specific food types [21]. By highlighting the benefits and disadvantages associated with precooling methods, some advantages include increased lifespan and improved performance of devices, as well as reduced energy consumption. On the other hand, precooling can lead to increased maintenance costs and water or energy consumption, which must be taken into consideration [22]. Gas emissions from traditional vapor compression refrigeration systems used in food transport can account for up to 40% of greenhouse gas emissions caused by car engines. Therefore, it is promising to use a 1.0 kW generator in a truck with a power of 300 horsepower to operate precooling systems for food cooling in the future [23]. Finally, to successfully implement precooling, it is important to focus on providing uniform heat distribution, appropriate air velocity inside cooling facilities, and using advanced techniques to improve the cooling process. Additionally, further research should be conducted on influential factors such as heat radiation, uneven air velocity, and their impact on the cooling process [24].

2. Experimental setup and methodology

2.1. Experimental setup

Experimental setups are described as in Figure 1, which consists of a rectangular air channel (1) with a length of 2m and a cross-section of 30cm x 30cm. The channel is made of aluminum-coated polyurethane material with a thickness ranging from 200-25 micrometers. Air is rotated by a centrifugal blower (2), which acts as an electric motor whose speed is controlled. The blower is located inside the air channel, which can be controlled for air entry and exit. the first channel is connected to a second air channel (15) with the same specifications, used for air recycling to the first channel. The air inside the channel is cooled by passing it over a set of cooling coils (3) to reduce the air temperature. These coils act as the evaporators for a cooling cycle using (R-22) as the refrigerant for the vapor compression cycle, known as direct refrigeration. The vapor is drawn by the compressor (4), then the compressor transfers the heat to the condenser (5), which converts the vapor into liquid through condensation. The liquid refrigerant is throttled into low-temperature and low-pressure vapor by expansion valves (6). Selected food items (cantaloupe, red cabbage, eggplant) are placed in a designated area for testing inside the air channel called the food package (7).

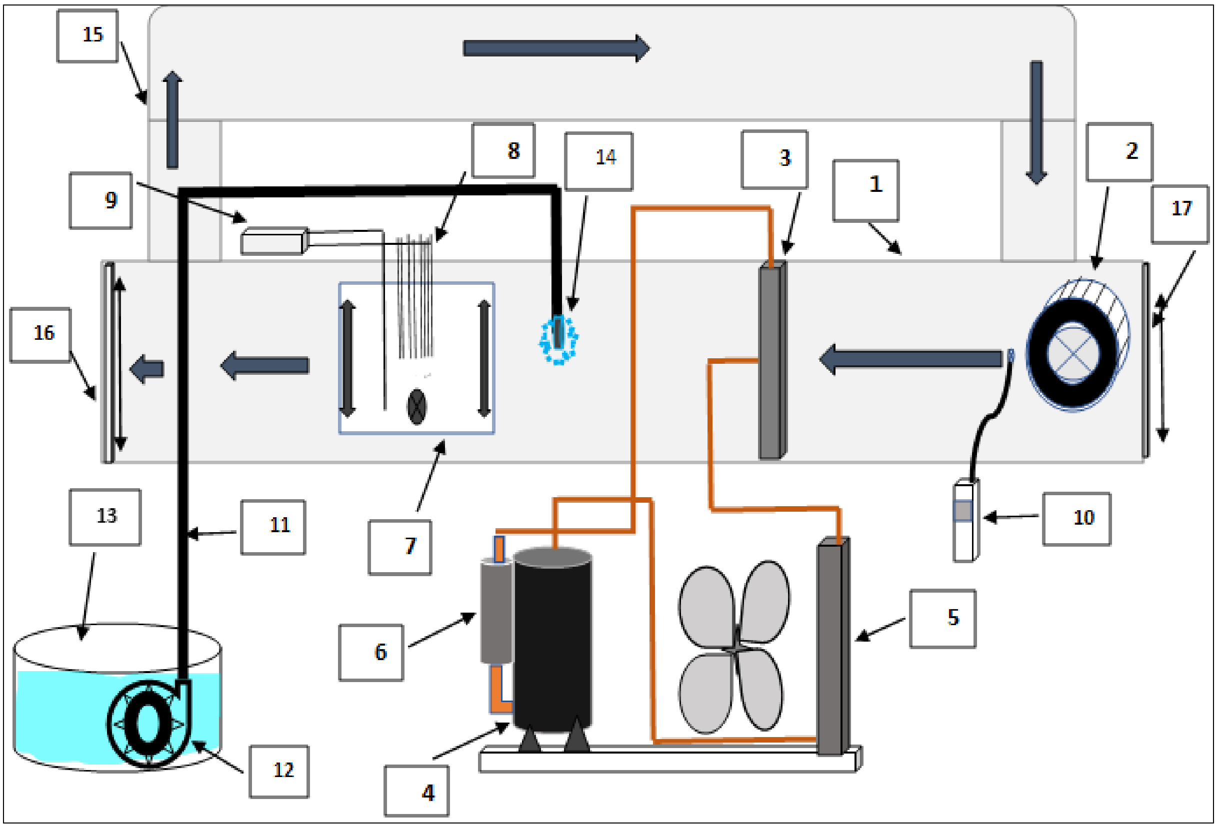


Fig 1: A diagram of the experimental setup of the device parts

Thermocouples (8) are used to measure temperature in specific parts inside food products. Eight thermocouples are placed at specific dimensions within the food items, with three sensors inside the cantaloupe, one of sensor at the centre (space), the second at a distance of 2 cm between the surface and the centre, and the third on the surface. three sensors inside the red cabbage, one in the centre 6.2cm away from the surface, one 3.1cm away from the surface, and one on the surface. In the eggplant experiment, two sensors are used, one in the centre 3cm away from the surface and one on the surface. Multiple sensors (9) are used to measure temperature and humidity outside and inside the air channel, while air velocity is measured using a digital moving anemometer (10). Food temperature is measured at regular intervals of two minutes for two hours during the cooling process, with cold air passing over the food package at specified rates of air-cooling speed (1.8, 3.6, and 4.8). The results are obtained by fixing the air velocity rate, closing the air outlet gate (16), and the inlet gate (17), and also by fixing the air velocity rate and using humidification at regular intervals of every 20 minutes for two minutes of humidification during the first hour, and then every 30 minutes for two minutes of humidification during the second hour, using an electric motor (12) to spray water from a water source (13) through water pipes (11) to the water mist (14) located inside the channel. The obtained results are used to draw cooling curves for the used food materials, including cantaloupe, red cabbage, and eggplant.

2.1. Methodology

It is possible to find the dimensionless temperature of food materials Y from the following equation:

$$Y = \frac{T - Ta}{Ti - Ta} \quad (1)$$

The linear part of the cooling curve for dimensionless temperature Y and cooling time t can also be represented by the following equation:

$$Y = je^{-ct} \quad (2)$$

It is also possible to find the cooling coefficient C at a specific air flow rate from the slope of the linear part of graph of the central logarithm dimensionless temperature using the following equation:

$$\lambda\iota = \sqrt[2]{\frac{ct}{Fo}} \tag{3}$$

From equations 4 and 5, the heat transfer coefficient from food materials to cold air can be calculated, such as depended by Albayati (2007) [1]:

$$\lambda\iota tan\lambda\iota = Bi \tag{4}$$

$$Bi = \frac{hR}{k} \tag{5}$$

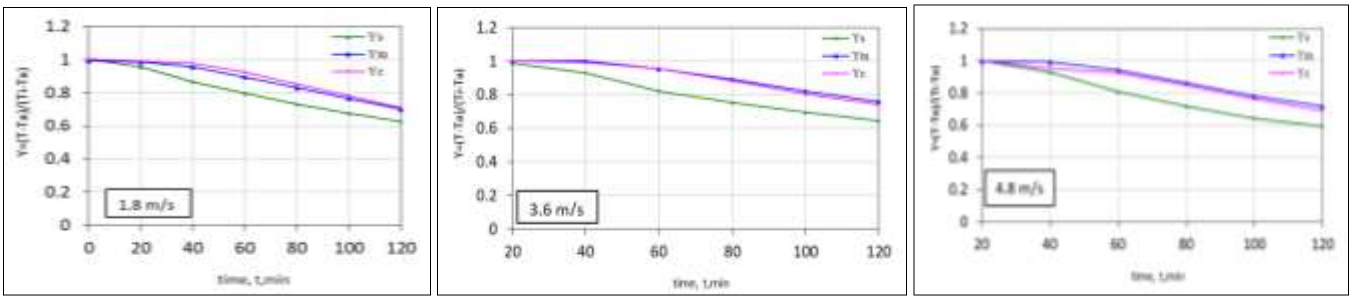
$$Re = \frac{Vd}{\nu} \tag{6}$$

$$Nu = \frac{hd}{k\alpha} \tag{7}$$

3. Results and Discussions

The results of pre-cooling studies on perishable food materials such as cantaloupe, red cabbage, and eggplant are being discussed below.

In Figure 2, which has been drawn, the cooling time for the cantaloupe and the dimensionless temperature Y rate are taken every 20 minutes for the cantaloupe in coordinate form. In this figure, three cooling curves are illustrated in three positions. The first curve represents the centre of the cantaloupe (the cavity) (R=d^2), the second curve is at the average distance between the surface and the centre, which is 2cm away, while the third curve, which is drawn, is on the surface of the cantaloupe (R=0). In this figure, air is passed over the cantaloupe at three consecutive speeds (1.8, 3.6, 4.8) with doors closed and air recirculated inside the channel, while the temperature of the air outside the channel ranges from (25.8-29.5). At an air speed of 1.8, after two hours of operation, from chart we observe a decrease in the dimensionless temperature rate of the cantaloupe in the three positions, with the surface experiencing the greatest decrease, while the decrease in the average and centre are fairly close to each other and less than the surface. We note that during the first 60 minutes of cooling, the dimensionless temperature on the surface decreases to 0.79, and from 60 to 120 minutes, it decreases to 0.625. When increasing the air blowing speed to the second speed (3.6) with the same air temperature and closing the doors, we observe an increase in the decrease of the dimensionless temperature rate of the cantaloupe in the three positions and after two hours later, where the dimensionless temperature rate becomes 0.59 at the surface, indicating that the rate of temperature decrease has increased with the increase in air blowing speed. By increasing the air blowing speed to 4.8 under the same conditions, after two hours, we observe an increase in the decrease of the dimensionless temperature rate of the cantaloupe, reaching 0.53 at the surface. We note that with an increase in the air blowing speed, the decrease in the dimensionless temperature rate increases, with the existence of some variation between the surface temperature and the other positions, which are somewhat close to each other.



A B C

Fig 2: Shows the dimensionless temperature variation of cantaloupe with the time curve of the pre-cooling process at different speeds (a) Air speed 1.8 m/s (b) Air speed 3.6 m/s (c) Air speed 4.8 m/s

In Figure 3, the cooling curves for the red coil are illustrated and drawn using the cooling time t and the dimensionless temperature rate Y. The temperature of the red cabbage is calculated at the centre (R=d/2), and at the average distance between the centre and the surface (R=d/4), and on the surface (the shell) where R=0. After the device is turned on, air is blown over the red coil at three speeds and the air temperature ranges from 25.8-29.5. The first speed, which is the lowest (1.8), involves closing the air inlet and outlet doors and relying on air recirculation. In this case, after two hours, the dimensionless temperature rates are observed at the average distance between the surface and the centre (0.675). From the graph, it can be noted that the dimensionless temperature rate decreases at the centre and the average distance, while it decreases more at the surface. At the second speed (3.6), with the doors closed and the same air temperature, after two hours, the dimensionless temperature rate in the average is (0.631). As for the maximum speed (4.8) with the doors closed and the same air temperature, after two hours, from the graph it can be observed that the dimensionless temperature rate in the average becomes (0.599). From the previous readings, it can be noted that increasing the air blowing speed increases the rate at which the temperature decreases at the centre, the average, and the surface. The difference between the centre, average, and surface temperatures also increases with increasing air blowing speed. depending on the average temperature at the distance between the surface and the centre at the lowest speed (1.8), the second speed (3.6), and the maximum speed (4.8) within a two-hour period, it can be observed that the time saved between the lowest and highest air blowing speeds is 32 minutes, which is 26.7%.

This means that it is possible to reach the dimensionless temperature rate at the average between the surface and the centre (0.675) by using the highest speed in just one hour and 28 minutes.

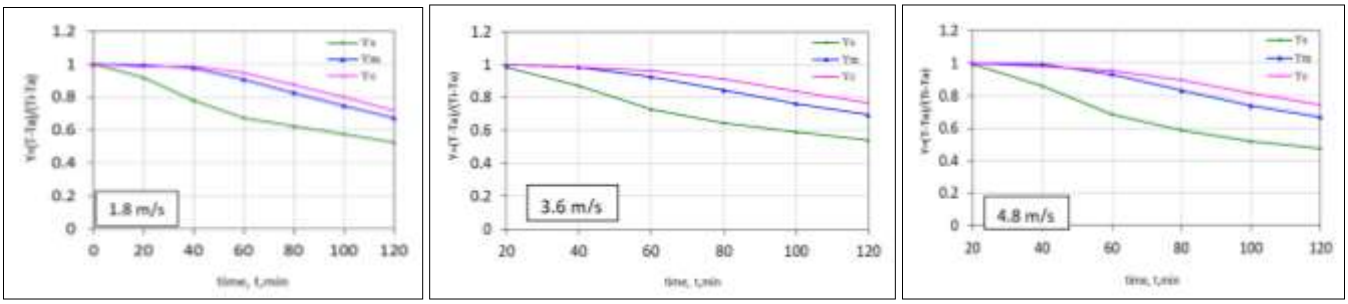


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Fig 3: Shows the dimensionless temperature variation of red cabbage with the time curve of the pre-cooling process at different speeds (a) Air speed 1.8 m/s (b) Air speed 3.6 m/s (c) Air speed 4.8 m/s

The cooling process of eggplants is studied as shown in Figure 4 by taking the cooling time (t) and the dimensionless temperature rate (Y) at regular intervals of 20 minutes. The temperature in the centre is calculated using three velocities and the same air temperature (25.8-29.5) over a period of two hours. The dimensionless temperature at the centre becomes (0.298) after two hours. The actual temperature at the centre becomes (5 °C), and the cold air temperature is (-1.94 °C) at the lowest speed (1.8). Increasing the air velocity to the second speed (3.6) leads to a dimensionless temperature of (0.42) and an actual temperature at the centre of (1.5 °C) and a cold air temperature of (-17.94 °C). Using the highest air velocity (4.8), the dimensionless temperature becomes (0.48) and the actual temperature at the centre is (0.5 °C), and the cold air temperature is (-18 °C). From data we notice that the dimensionless temperature rate increases as the cold air velocity increases due to the significant decrease in the cold air temperature and the proximity of the temperature in the centre to zero. This results in a decrease in the heat transfer process between the product and the cooling environment. Comparing the actual temperature at the centre at the lowest speed (1.8) is (5 °C) and at the second speed (3.6), it can be noted that increasing the air velocity to the second speed the temperature can reach a of (5 °C) at the centre within one hour and 24 minutes, saving 36 minutes which is 30% of cooling operation by increasing the air velocity to the second speed (3.6).

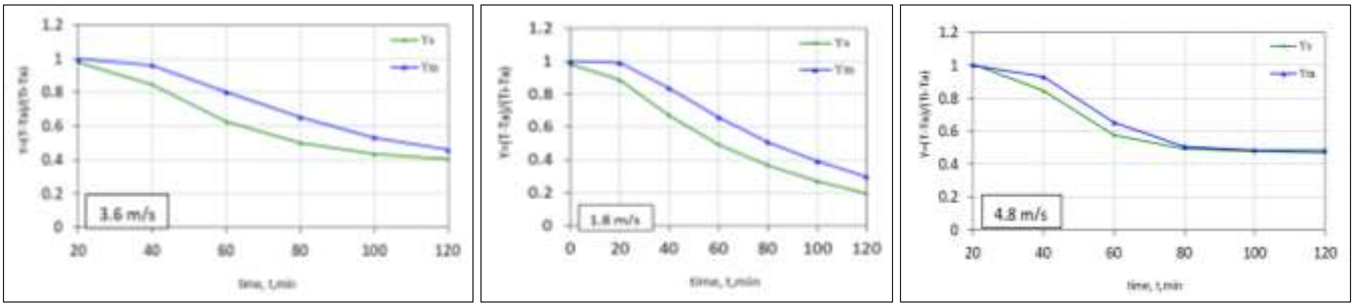

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Fig 4: Shows the dimensionless temperature variation of eggplant with the time curve of the pre-cooling process at different speeds (a) Air speed 1.8 m/s (b) Air speed 3.6 m/s (c) air speed 4.8 m/s

In Figure 5, dimensionless temperature (Y) curves are plotted for food products centre with a cooling time curve (t) to show the effect of air blowing speed at the lowest speed (1.8), the second speed (3.6), and the maximum speed (4.8) over a period of two hours. In cantaloupe, air blowing speed has a significant impact. After two hours, the dimensionless temperature at the centre at the lowest speed in cantaloupe reaches (0.7071), while the same temperature can be achieved at the maximum speed within one hour and 27 minutes, thus saving 33 minutes in cooling time or 27.5% less than at the lowest speed. In the case of red cabbage, the dimensionless temperature can reach (0.7181) at the centre in two hours by lowest speed while it can reach same degree (0.7181) in one hour and 24 minutes using the highest speed, saving 32 minutes or 26.6% of cooling time compared to the lowest speed for the same dimensionless temperature at the centre. As for eggplant, the temperature at the centre reaches (0.298) within two hours at the lowest air blowing speed, while at the highest speed, the dimensionless temperature reaches (0.485) during the same period. The inverse results in the dimensionless temperature Y in eggplant are due to the high temperature of the cold air (-17.94) and the low temperature at the centre of the eggplant (0.85), which reduces heat transfer between the product and its surrounding environment. These temperature values cause spoilage to eggplant over a short period of time.

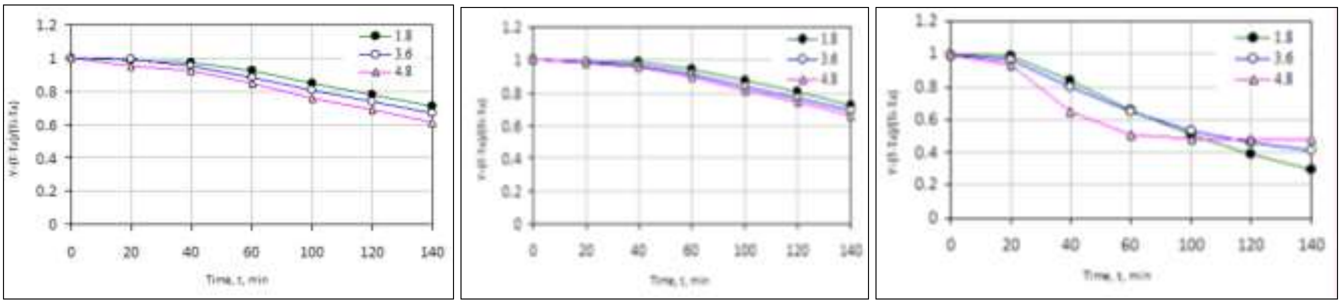

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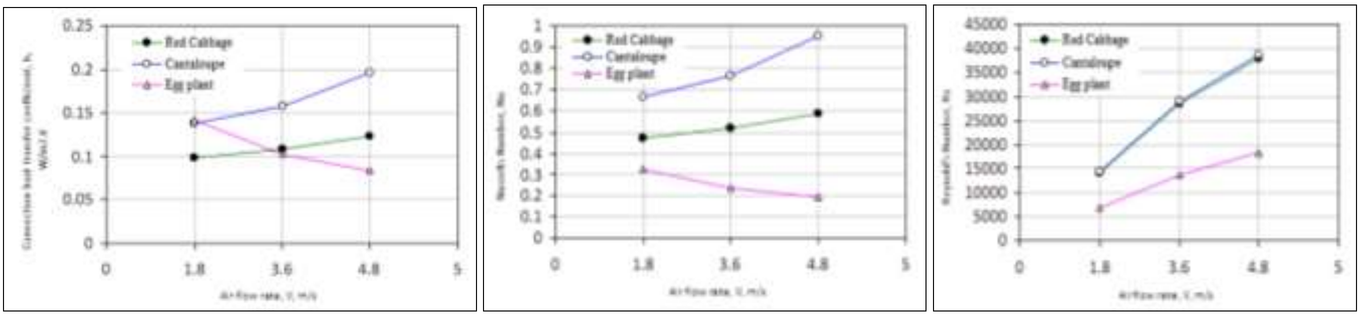
Fig 5: Variation of dimensionless temperature of food products at air velocities variation with time (a) Cantaloupe (b) red cabbage (c) Egg plant



A B C

Fig 6: Variation of heat transfer coefficient, Nusselt's number and Renold's number with air velocity (a) Air speed 1.8 m/s (b) Air speed 3.6 m/s (c) Air speed 4.8 m/s

The heat transfer coefficient h is the main factor relied upon in the heat transfer process from food products to cold air during cooling. Figure 6 illustrates the difference between the heat transfer coefficient h and the airflow rate. The heat transfer coefficient for cantaloupe is the highest among the food materials and increases with increasing airflow rate, while it is lower for red cabbage. As for eggplant, the heat transfer coefficient h gives inverse results as it decreases with increasing airflow rate. When the airflow rate increases from 1.8 to 4.8, the heat transfer coefficient in cantaloupe increases by 29.9% and increases by 19.3% in red cabbage, while it decreases by 40.3% in eggplant. Figure 6 also shows the correlation between the Nusselt number and the Reynolds number for both cantaloupe, red cabbage, and eggplant.

4. Conclusions

The following conclusions can be drawn from the above study:

1. Increasing the airflow rate leads to an increase in the heat transfer coefficient in cantaloupe and red cabbage. However, in eggplant, the heat transfer coefficient decreases with increasing airflow rate.
2. Increasing the airflow rate results in a significant decrease in the air temperature inside the air duct and a decrease in the temperature along half the radius of the food products. This leads to time and energy savings.
3. In cantaloupe and red cabbage, the dimensionless temperature Y increases with increasing airflow rate and in eggplant, the dimensionless temperature Y decreases with increasing airflow rate.

Nomenclature

Y - Dimensionless temperature
Bi - Biot number, hl/K
T - Temperature of product, C
Ta - Temperature of cold air, C
Ti - Initial temperature at the center of product, C
h - Heat transfer coefficient, W/m2 -C
k - Thermal conductivity of food product, W/m-C
ka -Thermal conductivity of air, W/m-C
Re- Reynold's number
Nu -Nusselt's number
V- Velocity of air, m/s
α - Thermal diffusivity, m2 /s
𝝀1 - 1st root of transcendental equation
𝝂 - Kinematic viscosity, m2 /s
Fo - Fourier number, αt/l2
C - Cooling coefficient, l/s
t - Time, s
d - Diameter, m
R - Radius, m
W- Water content by weight
j - Intercept

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