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Comparison of Pre-Cooling Unit with Normal Refrigeration under Control Atmosphere Storage

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Abstract
The availability of fresh vegetables in UAE especially in summer season has become a major issue as they are susceptible to post-harvest deterioration after harvest. Therefore, it is necessary to cool the product as quick as possible before it delivered to the customers. In present research work a comparison of pre-cooling unit with normal refrigeration was analyzed. The results revealed that for pre-cooling unit and normal refrigeration i.e. the average temperature ratio (TR_{avg}), cooling rate (CR) and mean half cooling time (Z) values were found to be (0.404, 0.221 ˚C/time and 55.21 minutes) and (0.556, 0.154 ˚C/time and 82.13 minutes) respectively. The curve produced strong relation between temperature ratio values (TR) and time in both cases i.e. pre-cooling and normal refrigeration having value of R^2 as 0.988 and R^2 as 0.978 respectively. Likewise, a linear regression was found between cooling rate values (CR) and time in both cases i.e. pre-cooling and normal refrigeration having value of R^2 as 0.9954 and R^2 as 0.9951 respectively. Furthermore, the study described that the pre-cooling unit saved 32.77% time to reduce the product temperature than normal refrigeration which is an ultimate gain.
Keywords: Pre-Cooling Unit, Temperature Ratio, Agriculture, Post-harvest Technology, Cooling Rate, Refrigeration Unit.

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INTRODUCTION

Pre-cooling is an important postharvest unit operation for tropical fruits and vegetables because of its short postharvest life. Even though it is desirable that the pre-cooling process be as fast as possible, the cooling should not result in any chilling injury to the fruits and vegetables (Baird *et al.,* 2001). The process of pre-cooling is the removal of field heat which arrest the deteriorative and senescence processes so as to maintain a high level of quality that ensures customer satisfaction (Niranjana *et al.,* 2009). Different pre-cooling methods employed to cool down the produce includes room cooling, forced-air cooling, hydro-cooling, package icing, vacuum cooling and cryogenic cooling. These methods use different modes and media for their function (Brosnan *et al.,* 2001). Dirty produce can introduce pests and moulds into the store. It has been observed through past surveys that losses in quantity and quality occur in fruits and vegetables after harvesting are estimated to be about 10% to 30% in developing countries (Kitinoja *et al.,* 2013).

Deterioration of fruits and vegetables during storage depends largely on temperature. One way to slow down this change and so increase the length of time fruits and vegetables can be stored, is by lowering the temperature to an appropriate level. It must be remembered that if the temperature is too low the produce will be damaged and also that as soon as the produce leaves the cold store, deterioration starts again and often at a faster rate (Kumar *et al.,* 2015). Tropical fruits and vegetables are harvested under ambient temperatures from 25 ^{o}C to 35 ^{o}C. Under this temperature, the respiration rate is high and the storage life is short. In many tropical countries, harvesting is done early in the morning to take advantage of lower temperatures. This practice however, may not be feasible for large growers that require the whole day to harvest their crop (Arshad *et al.,* 2014).

The primary focus of this research was to assess the performance of the pre-cooling unit by using the refrigerated air as the cooling medium with this system and its comparison with normal refrigeration. As during season period the storage time duration for storing the fresh cucumbers especially for the retail customers is very limited i.e. not more than 3 hours. Thus the time requirement in order to cool down the commodity is very crucial. In this research a pre-cooling unit was used to analyze the behavior of cucumber in terms of temperature ratio by using forced air-cooling technique. The air is forced through produce i.e.

cucumber packed in boxes / pallet bins. The performance of the pre-cooling system in terms of the temperature ratio, cooling rates and half cooling times of cucumber were evaluated for forced-air cooling technique accordingly.

MATERIALS AND METHODS

Location

The research work was carried out in the ADFSC Cold Store located at Western Region of Abu Dhabi, UAE in May, 2015. The pack house comprises of one big inbound area for intake / dispatch purpose, one large grading area with several grading tables, 11 cold rooms supplemented with automatic refrigeration and humidification equipments, a large parking area for company vehicles utilized for different operations and with more than 1000 manpower accordingly.

Control Atmosphere Storage

Fruits and vegetables have individual requirements for the amount of oxygen (O_2) and carbon dioxide (CO_2) necessary to stay fresh. Controlled atmosphere (CA) storage provides the precise environmental conditions needed for quality preservation. Air is comprised of about 21% oxygen, 78% nitrogen and other gases. This atmosphere, even when chilled to just above freezing, is not conducive to long-term storage of fruit and vegetables (Kader *et al.,* 2004). The subject cold store comprises of two large automatic refrigeration units, 1 big humidifier and a thermometer in order to maintain the desired temperature of vegetables accordingly. A large computerized touchpad automatic panel was also installed outside the subject cold room to control the temperature and humidity according to the vegetables desired need.

Pre-Cooling Unit (Forced Air Cooling Equipment)

Pre-cooling is a process of removing field heat from freshly harvested fruits or vegetables in a less time to prevent spoilage and maintenance of pre-harvest freshness and flavor (Kader *et al.,* 2002). The subject pre-cooling unit was comprised of 2 large fans protected with filters and the height of the unit was around 2 meters. Two motors i.e. 1 motor for each fan to run the fans was company installed and consume energy for about 3 KW – Hr / Hr accordingly. The RPM and Voltage was for the subject motors was 1420 rpm and 6.17 ampere respectively. A large company assembled computerized touchpad automatic panel with digital output was also installed on the pre-cooling unit in order to provide different indications to the system. The main display screen of the panel gives the system on/off indication, mode indication, product temperature probe set point indication, pre-cooler fans status, time of job in process, graphs and alarms indications to the user respectively. For the safe keeping of the motor a motor circuit breaker i.e. 6.3 - 10 Amp was also installed. In order to automatically safe the data log readings for product air temperature a Delta E Drive was installed which can be downloaded via USB disk.

Experimental Setup

In the preliminary step ten pallets of freshly harvested cucumber having high temperatures were selected, graded and packed in crates accordingly. Each pallet comprised of 30 crates respectively. Before the transference of finished goods inside the cold store, the temperature of the cold store was set through the cold store panel that 12^{o}C accordingly and the cutoff temperature range was set as 11^{o}C and 14^{o}C respectively. Then pallets was kept inside the cold store in two splits i.e. 5 pallets in-front of pre-cooling unit (force air cooling equipment) with proper covering and 5 pallets was placed near refrigeration unit without using pre-cooling unit respectively. With the objective to attain the minimum desired temperature of cucumber before dispatch, the time of 3 hours with temperature range 12^{o}C – 13^{o}C was set through the panel of the pre-cooling unit and the average initial temperatures of all ten pallets were recorded accordingly. Then after every 10 minutes of interval the temperature from all ten pallets was recorded accordingly. The average temperature readings resulting from the unit were used to plot the temperature-ratio curves accordingly. Then all the data analysis were done through analytical procedure in order to find out the temperature ratio, cooling rate and half cooling time for the unit accordingly. Finally, results obtained from the pre-cooling unit are compared with the observed data obtained from normal refrigeration accordingly.

Governing Equations Used for Temperature Ratio (TR), Cooling Rate (CR) and Half Cooling Time (Z)

The critical gathered observations and data for the trials were evaluated in terms of temperature ratio, cooling rates (CR) and half cooling time (Z) accordingly. Temperature ratio was derived by dividing the differences between initial product temperature (t_i) and the air temperature (t_a) by the difference between the product temperature (t) and the medium temperature (t_o) at any time duration. The equation for the temperature ratio calculation is appended below:

$$TR = t - t_o / t_i - t_a \quad \text{…. ...1}$$

Similarly, the cooling rate (CR) was determined by the statistical regression analysis method i.e. the slope of the cooling curve was plotted on a semi-log graph on an excel sheet and from which the cooling rate was calculated by following equation:

$$TR = j * e^{-CR} \quad \text{…….2}$$

Where; J = Lag Factor

e = Time

Likewise, the half cooling time was determined from the temperature ratio-time response of the cucumber during cooling. The time corresponding to a temperature ratio of 0.5 was taken as the half cooling time. The equation for the calculation of half cooling time is appended below:

$$Z = \ln (j*2) / CR \quad \text{…… 3}$$

RESULTS AND DISCUSSION

The present research was carried out to assess the performance of pre-cooling unit by using the refrigerated air as the cooling medium and it comparison with normal refrigeration method. The subject study revealed that the analytical parameters studied during this research were differed very significantly for the case of cucumber under controlled atmospheric conditions. The pre-cooling unit used in this research was able to reduce the temperature of the cucumbers upto 12^{o}C approximately within 3 hours as compared to normal refrigeration. The results of the cooling times observed from the selected produce i.e. cucumber using the forced air cooling method were evaluated in terms of temperature ratio (TR), cooling rates and half cooling times in the different locations of the produce. Table (1) showed the results for different calculated parameters for temperature ratio for cucumbers by using forced air cooling and normal refrigeration methods. By using these obtained values the cooling rate and the mean half cooling time was determined accordingly.

Table 1. Summary results for different statistical parameters calculated for pre-cooling unit and normal refrigeration

Time Minutes	Product Temperature (^{o}C)		Temperature Ratio (TR)		Cooling Rate (CR)	
	Normal Refrigeration ^{o}C	Pre-Cooling ^{o}C	Normal Refrigeration	Pre-Cooling	Normal Refrigeration ^{o}C/time	Pre-Cooling ^{o}C/time
0	16.5	16.5	1	1	0	0
10	16.2	16.1	0.969	0.956	0.002	0.006
20	15.9	15.6	0.899	0.856	0.006	0.008
30	15.6	15.2	0.829	0.756	0.033	0.047
40	15.2	14.7	0.759	0.656	0.048	0.068
50	15.0	14.3	0.689	0.556	0.076	0.109
60	14.7	13.9	0.618	0.451	0.097	0.139
70	14.5	13.7	0.553	0.402	0.118	0.169
80	14.3	13.5	0.507	0.356	0.145	0.207
90	14.1	13.3	0.475	0.311	0.159	0.227
100	14.0	13.1	0.445	0.267	0.165	0.250
110	13.9	13.0	0.412	0.231	0.189	0.270
120	13.9	12.9	0.395	0.203	0.204	0.292
130	13.7	12.7	0.370	0.178	0.232	0.331
140	13.7	12.6	0.359	0.144	0.252	0.360
150	13.6	12.5	0.343	0.122	0.268	0.383
160	13.5	12.4	0.328	0.101	0.286	0.409
170	13.4	12.3	0.312	0.078	0.309	0.441
180	13.4	12.2	0.297	0.056	0.335	0.478

From the obtained results of different statistical parameters for pre-cooling unit i.e. the average temperature ratio (TR_{avg}), cooling rate (CR) and mean half cooling time (Z) values are found 0.404, 0.221 ^{o}C/time and 55.21 minutes respectively. Similarly, the obtained results from normal refrigeration i.e. the average temperature ratio (TR_{avg}), cooling rate (CR) and mean half cooling time (Z) values are found 0.556, 0.154 ^{o}C/time and 82.13 minutes respectively. Furthermore, the exponential regression in terms of power form among the values of temperature ratio (TR) obtained experimentally vs time duration (minutes) was developed.

The curve produced strong relation between temperature ratio values (TR) and time in both cases i.e. pre-cooling and normal refrigeration having value of R^2 as 0.988 and R^2 as 0.978 respectively. In both cases it has been observed that initially the temperature decreases quickly and after sometime this decrease in temperature becomes slow. However, due to the impact of forced air cooling the intensity of cooling was found faster in pre-cooling than the normal refrigeration respectively. This power relation could be the representative for calculating the value of Temperature Ratio for the corresponding value of any time duration. The present findings are in agreement with (Arshad *et al.,* 2015; Baird *et al.,* 2001; Kumar *et al.,* 2015) for cucumber, tomatoes and mangoes respectively.

Likewise, a linear regression was found between cooling rate values (CR) and time in both cases i.e. pre-cooling and normal refrigeration having value of R^2 as 0.9954 and R^2 as 0.9951 respectively. In both cases it has been observed that the cooling rate was increases with the passage of time with the decrease in temperature respectively. However, due to the impact of forced air cooling the efficiency of cooling was found faster in pre-cooling than the normal refrigeration respectively. Similar findings were observed by (Niranjana *et al.,* 2009) for bananas. Furthermore, it has been observed that the total cooling time duration for the case of pre-cooling

unit (110.42 minutes) was found 32.77% less then and normal refrigeration (164.26 minutes) respectively which describes that pre-cooling unit is dominant over normal refrigeration. Such graphs are illustrated in (Figure 1 till Figure 4) accordingly.

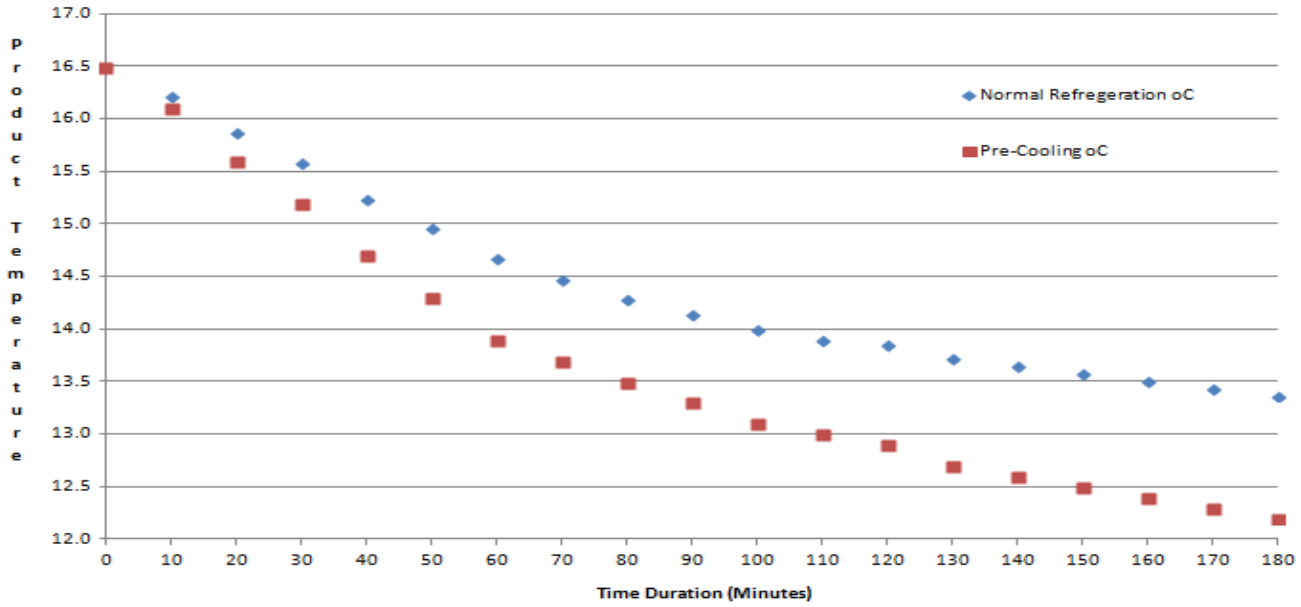

Fig. 1. Comparison of temperature profile as a function of time for normal refrigeration and pre-cooling unit.

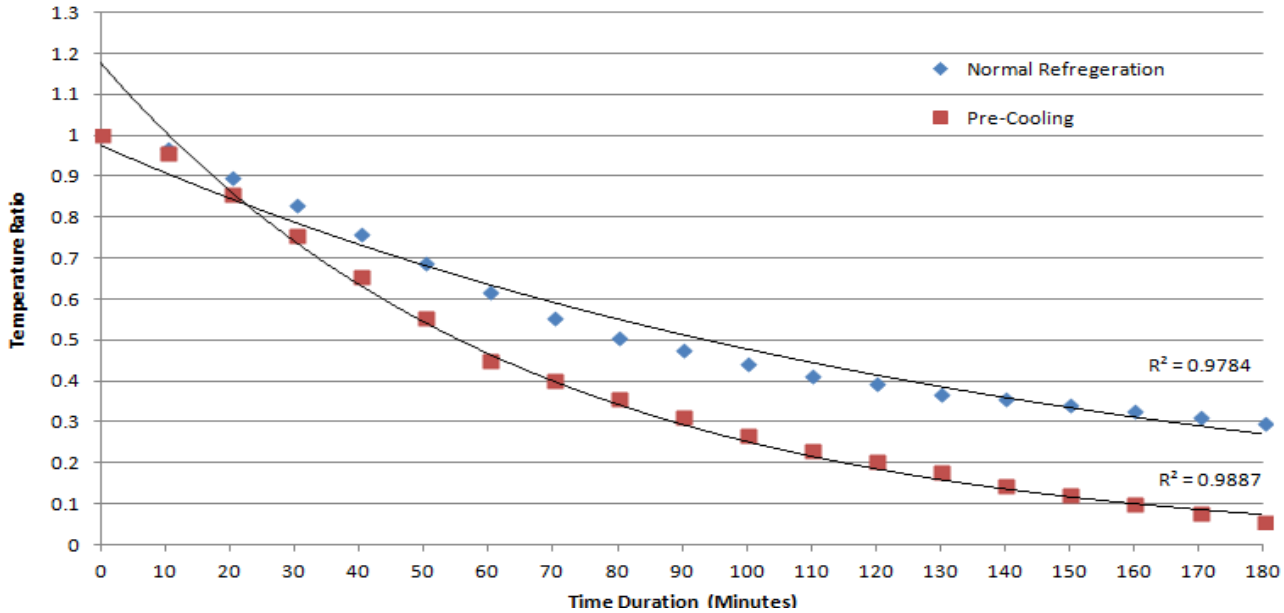

Fig. 2. Comparison of Temperature Ratio (TR) profile as a function of time for normal refrigeration and pre-cooling unit.

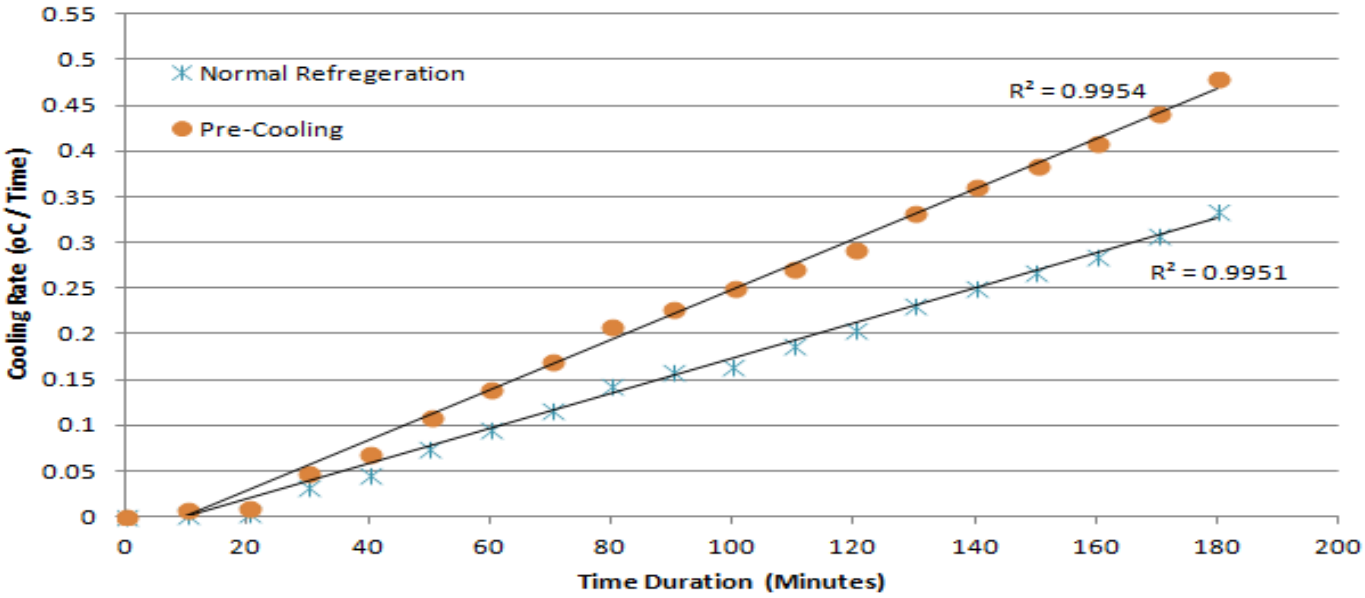

Fig. 3. Comparison of Cooling Rate (CR) as a function of time for normal refrigeration and pre-cooling unit.

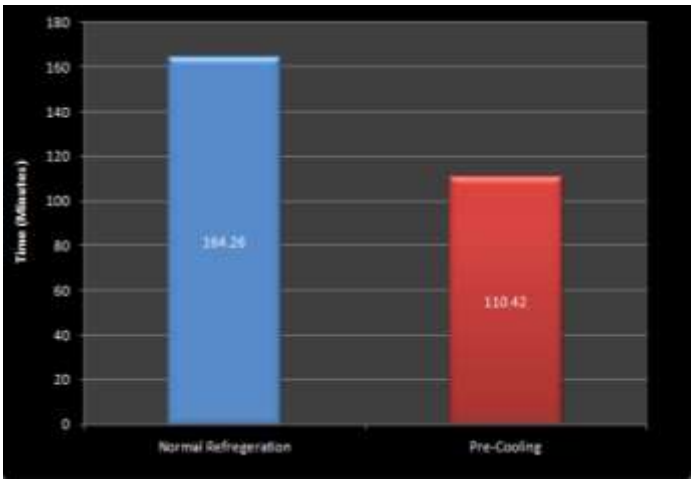

Fig. 4. Total time consumed in pre-cooling unit over normal refrigeration to cool down the product till desired level

CONCLUSION

The study concludes that the pre-cooling unit used in this research was able to reduce the temperature of the cucumbers upto 12^{o}C approximately within the time range of 3 hours and therefore, dominant over normal refrigeration. From the obtained results for pre-cooling unit and normal refrigeration i.e. the average temperature ratio (TR_{avg}), cooling rate (CR) and mean half cooling time (Z) values are found to be (0.404, 0.221 ^{o}C/time and 55.21 minutes) and (0.556, 0.154 ^{o}C/time and 82.13 minutes) respectively. The curve produced strong relation between temperature ratio values (TR) and time in both cases i.e. pre-cooling and normal refrigeration having value of R^2 as 0.988 and R^2 as 0.978 respectively. Likewise, a linear regression was found between cooling rate values (CR) and time in both cases i.e. pre-cooling and normal refrigeration having value of R^2 as 0.9954 and R^2 as 0.9951 respectively. Hence, the pre-cooling unit saved 32.77% time to reduce the product temperature than normal refrigeration which is an ultimate gain.

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CONFLICT OF INTEREST

There is no conflict of interest.

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