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Assessment of the Performance of Pre-Cooling Unit under Control Atmosphere Storage

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Abstract: Pre-cooling is a process of removing field heat from freshly harvested fruits or vegetables in a sufficient time to prevent spoilage and maintenance of pre-harvest freshness and flavor. Usually most produce is pre-cooled just before loading for transport to market or before short or long term storage. 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. From the obtained results of different statistical parameters i.e. the average temperature ratio (TR_{avg}), cooling rate (CR) and mean half cooling time (Z) values are found to be 0.415, 0.228°C/time and 68.81 minutes respectively. Thus, thorough the results it is clear that the total cooling time duration for the cucumber pre-cooling should to be (68.81*2) i.e. 137.62 minutes respectively to get the desired temperature before dispatch. The temperature beyond this time duration seems to be un-economical and wasteful practice. For the calculation of temperature ratio (TR) through the pre-cooling unit the exponential curve for TR values must be used to obtained the actual temperature ratio. The empirical equation developed for calculating TR values can be used. As the produce study was cucumber; therefore this empirical equation is valid only for cucumbers while the results may vary for other types of produce.

Key words: Pre-Cooling Unit · Temperature Ratio · Agriculture · Post Harvest Technology · Cooling Rate · Refrigeration Unit

INTRODUCTION

Cold storage of fruits and vegetables was used extensively by our ancestors to keep food after the harvest season. In modern times, the year round availability of fresh produce in the supermarket has reduced the use of home storage. However, even today there are benefits of home storage, which make it a good alternative to buying produce from the store. It is essential that fruits and vegetables are not damaged during harvest and that they are kept clean. Damaged and bruised produce have much shorter storage lives and very poor appearance after storage. 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 [1].

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 [2].

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Tropical fruits and vegetables are harvested under ambient temperatures from 25°C to 35°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.

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. In addition to this forced-air cooling is the most widely adaptable method and is commonly used for many fruits and vegetables to remove the field heat from freshly harvest produce in minimum time [3]. Pre-cooling is a process of removing field heat from freshly harvested fruits or vegetables in a sufficient time to prevent spoilage and maintenance of pre-harvest freshness and flavor [4]. Usually most produce is pre-cooled just before loading for transport to market or before short or long term storage [5]. Pre-cooling also reduces bruising damage from vibration during transit and reduces the amount of refrigeration required during transport. Today pre-cooling systems applies the concept of cooling mediums such as water or air, or a combination of both so that heat is transferred from the product to the medium [6].

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. 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.

Objectives: The potential motive of the subject research work is to assess the performance of pre-cooling unit by using the refrigerated air as the cooling medium with this system in terms of the temperature ratio, cooling rate and half cooling time, to develop the graph for temperature-ratio vs time response and to develop the equation for temperature ratio for pre-cooling unit for the case of cucumber under controlled atmospheric conditions.

MATERIALS AND METHODS

Location: The research work was carried out in the ADFSC Cold Store (pack house) located at Madinat Zayed (Badazayed), Western Region of Abu Dhabi, UAE in November, 2014. 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 (0_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 [7]. 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. Figs. 1(a) – 1(d) describes the different views of the subject cold store room utilized in this research.

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 [8]. 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

Fig. 1a: Main Access Way for MZ Cold Stores

Fig. 1b: Front View of Subject Cold Room Selected for Pre-Cooling Study

Fig. 1c: Refrigeration Equipment

Fig. 1d: PLC Control Panel

Fig. 2a: Front View Pre-Cooling Unit

Fig. 2b: Back View Pre-Cooling Unit

Fig. 2c: Company Assembled Fans with 3KW-Hr/Hr Motor

Fig. 2d: Control Panel Along With U-Tube Manometer of Pre-cooling Unit

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. Figs. 2(a) – 2(d) describes the different views of the subject pre-cooling unit used in this research.

Experimental Setup: In the preliminary step five pallets of freshly harvested cucumber having high temperatures were selected, graded and packed in crates accordingly. Before the transference of finished good inside the cold store the temperature of the cold store was set through the cold store panel that 12°C accordingly and the cutoff temperature range was set as 11°C and 14°C respectively. Then after the grading operation, the subject pallets kept inside the cold store in-front of pre-cooling unit and covered properly. With the objective to attain the minimum desired temperature of cucumber before dispatch the time of 3 hours with temperature range 12°C – 13°C was set through the panel of the pre-cooling unit and the average initial temperatures of all five pallets were recorded accordingly. Pressure drop across the fan was measured using a U-Tube manometer. Then after every 10 minutes of interval the temperature signals from the whole unit i.e. from the produce and air used within the system was recorded at different location manually and cross checked by the data recorded by the company fitted temperature sensor in a pre-cooling unit accordingly. The average temperature readings resulting from the unit were used to plot the temperature-ratio curves accordingly. Finally 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. Figs. 3a – 3e elaborates overall experimental operation pictorial view observed during this research period.

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:

$$TR = t - t_o / t_i - t_a \quad (1)$$

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:

$$TR = j * e^{-CR} \quad (2)$$

Fig. 3a: Checking of Pre-Cooling Unit Condition before Running an Experiment

Fig. 3b: Taking Initial Temperature Readings for Cucumber

Fig. 3c: Full View Pre-Cooling Unit after Covering

Fig. 3d: Operating the Pre-cooling Unit through PLC Panel of a Machine

Fig. 3e: Manual Checking of Temperatures at Different Time Intervals to Get Accuracy

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:

$$Z = \ln (j*2) / CR \quad (3)$$

RESULTS AND DISCUSSION

The subject research was carried out to assess the performance of pre-cooling unit by using the refrigerated air as the cooling medium. 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°C approximately within 3 hours. 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 shows the results for different calculated parameters for temperature ratio for cucumbers by using forced air cooling method. By using these obtained values the cooling rate and the mean half cooling time was determined accordingly.

From the obtained results of different statistical parameters i.e. the average temperature ratio (TR_{avg}), cooling rate (CR) and mean half cooling time (Z) values are found 0.415, 0.228°C/time and 68.81 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 having value of R2 as 0.986. Therefore, this power relation could be the representative for calculating the value of Temperature Ratio for the corresponding value of any time duration. Such graph is illustrated in Fig. 4 accordingly.

The equation in the Fig. 4, gives the relation between the Temperature Ratio (TR) and Time duration (minutes). From this empirical equation the relation of temperature ratio can be calculated of any time duration. Following equation can be used for calculating Temperature Ratio value for the case of cucumber only.

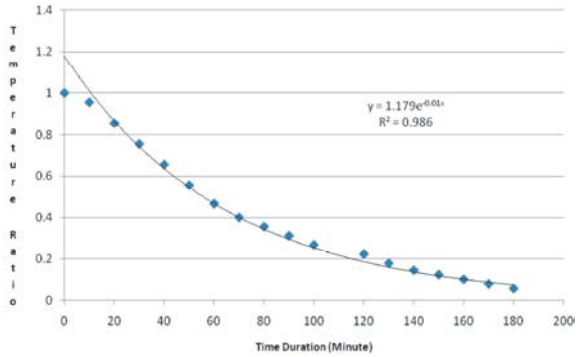

Fig. 4: Regression in terms of power form between experimental (TR) and time duration.

Table 1: Summary results for different statistical parameters calculated for pre-cooling unit by using forced air cooling method

Time	Product Temp	Temp Ratio	Lag Factor	Log J	Log TR	CR
Mints	°c	TR	J			
0	16.5	1	1	0	0	---
10	16.1	0.956	0.911	-0.040	-0.019	-0.02
20	15.6	0.856	0.878	-0.056	-0.067	0.008
30	15.2	0.756	0.889	-0.051	-0.121	0.047
40	14.7	0.656	0.844	-0.073	-0.183	0.068
50	14.3	0.556	0.852	-0.069	-0.255	0.109
60	13.9	0.467	0.826	-0.082	-0.330	0.139
70	13.7	0.4	0.895	-0.048	-0.397	0.189
80	13.5	0.356	0.882	-0.054	-0.449	0.207
90	13.3	0.311	0.867	-0.062	-0.507	0.227
100	13.1	0.267	0.846	-0.072	-0.574	0.250
120	12.9	0.222	0.818	-0.087	-0.653	0.272
130	12.7	0.178	0.778	-0.109	-0.750	0.303
140	12.6	0.144	0.857	-0.066	-0.840	0.360
150	12.5	0.122	0.833	-0.079	-0.912	0.383
160	12.4	0.1	0.800	-0.096	-1	0.409
170	12.3	0.078	0.750	-0.124	-1.109	0.441
180	12.2	0.056	0.667	-0.176	-1.255	0.478

$$TR = 1.179 * e^{-0.01(T)} \quad (4)$$

where
TR = Temperature Ratio
T = Time Duration

CONCLUSIONS

The outcome of the conducted research in the ADFSC Cold Store (pack house) located at Madinat Zayed (Badazayed), Western Region of Abu Dhabi, UAE tantamount that the pre-cooling unit used in this research was able to reduce the temperature of the cucumbers upto 12°C approximately within range time provided i.e. 3 hours. Cucumbers can be rapidly cooled by forced air cooling method by using refrigerated as a medium. From

the obtained results of different statistical parameters i.e. the average temperature ratio (TR_{avg}), cooling rate (CR) and mean half cooling time (Z) values are found to be 0.415, 0.228 °C/time and 68.81 minutes respectively. Thus, thorough the results it is clear that the total cooling time duration for the cucumber pre-cooling should to be 68.81 * 2 i.e. 137.62 minutes respectively to get the desired temperature before dispatch. The temperature beyond this time duration seems to be un-economical and wasteful practice. For the calculation of temperature ratio (TR) through the pre-cooling unit the exponential curve for TR values must be used to obtained the actual temperature ratio. The empirical equation developed for calculating TR values can be used. As the produce study was cucumber; therefore this empirical equation is valid only for cucumbers while the results may vary for other types of produce.

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