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Pre-Cooling and Temporary Storage of Apple Fruits

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ABSTRACT

A Laboratory study was carried out to test and evaluate a portable pre-cooling unit for apple fruits. The effect of pre-cooling process on safe storage of the pre-cooled apple in comparison with the non-cooled samples was also determined during temporary storage process under cooled storage condition. A laboratory experiments were conducted at three different levels of water temperature (3, 5 and 8 °C), three different levels of water flow rate (5, 8 and 11 L / min) and two volumes of fruits (medium and large). The results showed that, rapid drop in apple temperature at the early stage of cooling process and the cooling rate starts to decline as the product temperature approached the temperature of the cooling water. The values of cooling coefficient (C) increased with the increase of water flow rate, decrease of fruit volume and decrease of cooling water temperature. The half and seven-eighth cooling times were decreased with the increase of water flow rate, while they were increased with the increase of water cooling temperature and fruits volume. The storage experiments showed that, the pre-cooled apple fruits recorded lower loss in moisture, lower total soluble solids, higher fruit firmness and higher total sugar content in comparison with the non cooled samples.

INTRODUCTION

Apple is one of the most important tree fruit of the world belongs to the family Rosaceae and sub-family Pomoidae. Apple is a typical temperate tree fruit with more than 80 %of the world's supply being produced in Europe. (Ahsan *et al.*, 2008; Wani *et al*., 2009). In Egypt apple trees concentrated in Nubaria, Cairo- Alexandria desert road and Al Khatatba. While; inside the valley, it has grown in Behera and Gharbia.In 2016 area harvested 69657 faddan with production of 731454 ton according to FAO (2016). Most of these areas are new reclaimed land.

After harvest, apple fruits are susceptible to deterioration and it is necessary to cool them down as quick as possible. One important factor which is often under emphasized when considering the cooling of apple fruits is the lag time between harvesting and the commencement of pre-cooling. Delayed pre-cooling increased the loss of moisture, lowers tissue firmness, and increased metabolic activities in fruits (Mahesh, 2007).

Reducing the temperature of apple fruits immediately after harvest greatly reduces respiration rate, extends shelf-life, and protects produce quality, while reducing volume losses by decreasing the rates of moisture loss and decay. This first cooling step is usually referred to as "pre-cooling" since it is done as soon as possible after harvest and ideally accomplished before produce is placed into cold storage or loaded into refrigerated trucks or marine containers for shipment to market (Lisa and thompson. 2010).

Wijewardance and Guleria (2009) reported that pre-cooled apple fruits exhibited relatively slower loss in weight on the corresponding dates as compared to those without pre-cooling. This may be due to the slower loss of moisture from precooled commodities when higher relative humidity is maintained in the storage atmosphere. Such conditions can easily be achieved by lowering the temperature as the storage environment tends to be more saturated simply by reduction in temperature.

There are several hydro-cooler designs in operation commercially. Hydro-cooling methods differ in their cooling rates and overall process efficiencies. Differences between the individual techniques are evident by the method of cooling and by the way that produce is moved or placed in the cooler. Various types of hydro-cooler are available, some of which include conventional (flood) type, immersion type, and batch type (Brosnan and Da-wen 2003).

The problem of apple marketing and storing in Egypt is the short duration of quality retention after harvest. This condition may be attributed to the lack in proper post harvest and handling practices specially pre-cooling after harvest (MOA, 2014).

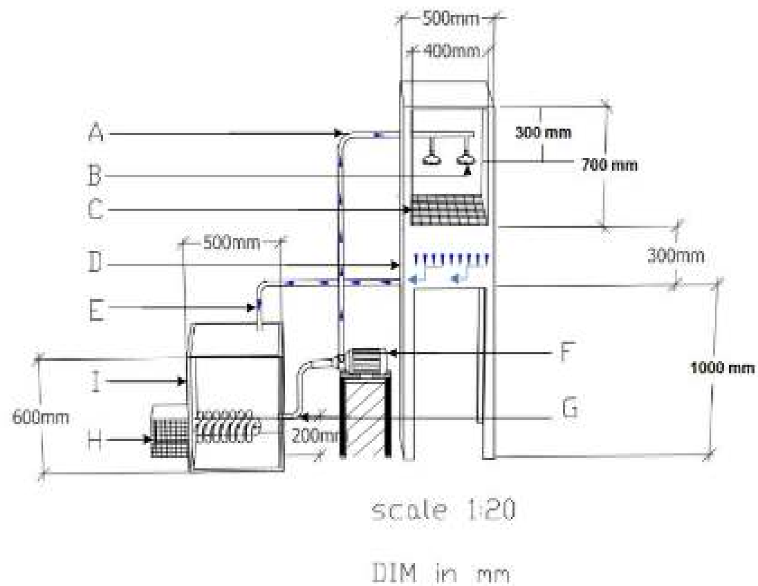
The current study aims to test and evaluate the effect of pre-cooling process (hydro-cooling) on quality retention of Egyptian apple (Malus Domestica. var. Anna) during storage process.

MATERIALS AND METHODS

This study was carried out at the laboratory of food Processing Engineering, Agriculture Engineering Department, Faculty of Agriculture, Mansoura University in August, 2015. The experimental work was divided into three stages; the first stage included fabrication of a portable pre-cooling unit (Hydro-cooling); the second stage was proceeded to determine the cooling rate (half and seven eighth cooling times) and the refrigeration load of apples; the third stage included storage of the pre-cooled apples in a refrigerator to determine the quality changes of the pre-cooled apple in comparison to the non pre-cooled. Freshly harvested apple fruits at maturity stage (red color) were used for the experimental work. The tested fruits were obtained from an apple orchad and its initial moisture content was determined according to (AOAC 37.1.10(AOAC Official Method 934.06 Moisture in Dried Fruit) and TS 3688 ISO 7701) from 78 to 82 % w.b.

The Pre-cooling Unit:

Fig. (1) illustrates a general view of the portable pre-cooling unit used for the experimental work. The main frame of the cooling unit was constructed of 50 mm iron angles with dimensions of 500 mm long, 500 mm wide and 1000 mm high. The main frame was fixed on iron base constructed of 500×500 mm angle blades carried by four iron columns 1000 mm high. The cooling chamber was installed on the top section of the main frame. The chamber frame was covered by double galvanized steel sheets (12.5 mm thick) filled with foam sheets to prevent heat transfer from the sides of the chamber. A door was assempled on the front side of the chamber frame to charge and discharge the product. For the hydro-cooling process, two sprayers were fixed at a distance of 300 mm from the ceiling of the cooling chamber and 400 mm from the stainless net which used for crop accommodation. A main water tank with dimensions of 500 mm long, 500 mm wide and 600 mm high was used for water supply to the water sprayers via a 0.5 kW water pump. For the cooling process, ferion cooling unit with the following specification (Danfoss SC15B, 104L, 2830, 220-240V, 50HZ 1PH LBP/HBP made in Germany) was installed to the main water tank. Meanwhile, a return water tank with dimensions of 500 mm long, 500 mm wide and 300 mm high was installed under the stainless steel net of the cooling chamber for collecting the cooled water passed through the product and return it to the main cooling tank.



Tube	A
Sprayers	B
Stainless Steel Net	C
Water return tank	D
Returned tube	E
Water pump	F
evaporator	G
Cooling unit	H
Main Water tank	I

Fig. 1. Schematic diagram for the portable pre-cooling unit

Fig. 2. General view of the portable pre-cooling unit.

Experimental Treatments:

The laboratory experiments were conducted under three different levels of water temperature (3, 5 and 8 °C), three levels of water flow rate (5, 8 and 11 L / min) and two volumes of apple fruits (large as diameter 64-70 mm and medium as diameter 50-58 mm).

Experimental Measurements and Test Procedure:

During the course of experimental work, several measurements were conducted either directly or indirectly depending on the nature of measurement itself. These measurements included fruit core temperature, water temperature, flow rate of water, product weight, fruit firmness, total sugar content and total soluble solids.

Pre-cooling experiments:

During the pre-cooling process, the apple core temperature was measured using a digital temperature measuring equipment (Data logger). The temperatures were measured at 12 different locations.

Temperature data was stored within the unit and could be transferred to a printer or pc. Copper- constantan thermocouples were placed at the core of apple fruits to determine the temperature changes. A small ring clay was placed around the thermocouple sensors where it was inserted into the product to prevent juice leakage and prevent inserting water into the product. The water temperature was checked using thermocouple installed in the chamber of cooling water and communicated to one of the channels of data logger.

Half and seven-eighth cooling times:

Regression analysis was carried out for the dimensionless temperature data in the exponential form (temperature ratio) to determine the half and seven – eighth cooling times of the tested apple fruits using the equation of (Dincer *et al*. 1992 and Shoker *et al*. 1994) as follows:

$$\theta = J \exp(-Ct) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

Where;

θ : Temperature ratio. J : Lag factor.
C : Cooling coefficient, min^{-1}. t : time, min.

Then, The half (H) and seven-eighth (S) cooling times were calculated by means of the following equations (Dincer *et al*. 1992 and Shokr *et al*. 1994):

$$H = \frac{\ln 2J}{C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$S = \frac{\ln 8J}{C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.(3)$$

Refrigeration Load:

The actual refrigeration capacity of the pre-cooling unit was calculated using the following equation sited by (Radwan, 2010).

$$P = \frac{M\,(Ti - Tw) \times 1.28}{S} \quad \ldots\ldots\ldots\ldots.(4)$$

Where: P = product refrigeration load, W
M = product mass, Kg
S = seven-eighth cooling time, h
T_i = initial temperature of the product to be cooled, °C
T_w = temperature of cooling water, °C

As stated by (Thompson *et al*. 1998) and for a well insulated coolers used for the fast cooling of fresh produce, "more than 80% of the total refrigeration capacity is available for the cooling of the product". The remaining 20% is used to cope with extraneous heat load. The total heat capacity required may be estimated as follows (Thompson *et al*. 1998);

$$P_t = P \times 1.25 \quad \ldots\ldots\ldots\ldots\ldots\ldots..(5)$$

Where: P_t = total refrigeration load, W.

Storage experiments:

Two different sets of pre-cooled and non pre-cooled apple fruits were stored in a refrigeration unit after packing in three layers plastic bags used for fruits storage and handling. The refrigeration unit was adjusted at 3°C as the optimum temperature for cooled storage of apple fruits (John *et al*. 2004). Samples of the stored apples were taken every 3 days of the storage process. Quality evaluation tests of the samples (weight loss, fruit firmness, total soluble solids and total sugar) were conducted for the pre-cooled and non pre-cooled apple fruits.

The weight of apple samples was measured using an electric digital balance model EK-200 GD with maximum capacity of 200 g and accuracy of 0.01g. Fruit firmness was measured using fruit pressure tester (Penetrometer). The sugar content was measured using A spectrophotometer (model z anway 6405 / z is.). The total soluble solids was measured using a hand refractometer (model z ali 110).

RESULTS AND DISCUSSION

Fig. (2) illustrates the changes in apple fruits core temperature as related to cooling time at cooling water temperature of 3°C and different water flow rates. The obtained data showed that, the fruits with large volume need longer time to reach the desired core temperature than the fruits of medium volume. Also, it has showed that, cooling time for both fruits volumes was decreased with the increased of cooling water flow rate from 5 to 11 L / min, the cooling time decreased from (42 to 36 min) and from (36 to 30 min) for large and medium fruits volume, respectively.

Similar results were obtained for cooling water temperature of 5 and 8 °C. as shown in figs (3 and 4).

In general, rapid drop in product temperature was observed at the beginning of cooling process and the cooling rate starts to decline as the product temperature approaches the cooling water temperature. The cooling process is often approximated with the concept of half cooling time and seven – eighth cooling time. These two concepts represent the time required for the product temperature to drop half and seven–eighth the difference between the product initial temperatures and the cooling water temperature.

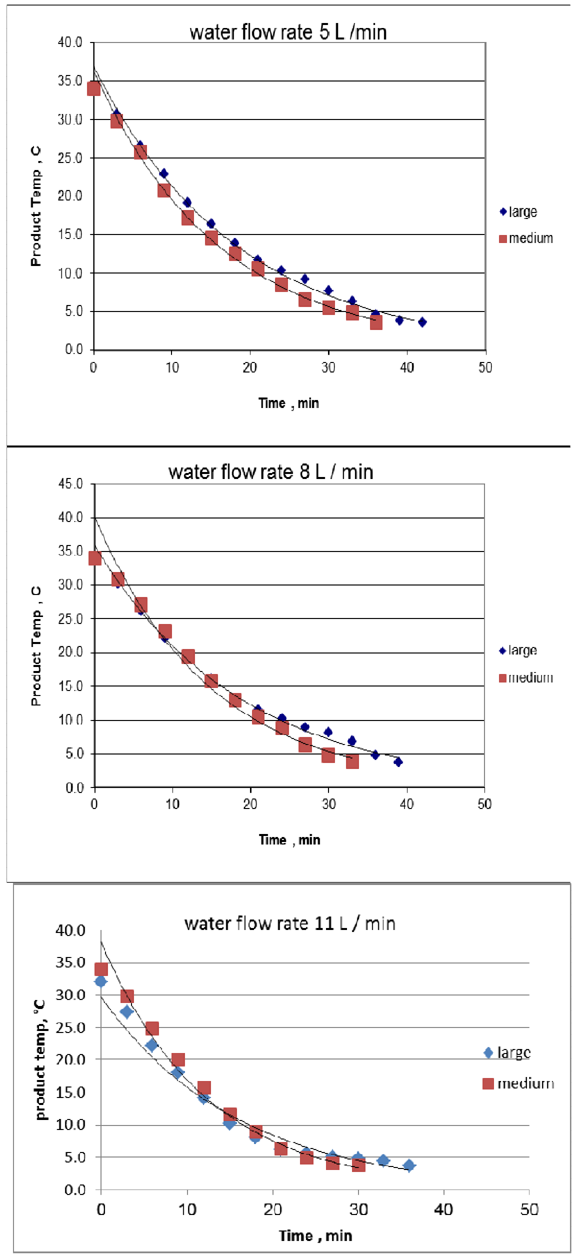


Fig. 3. Average core temperature of apple fruits as related to cooling time for water cooling temperature of 3 °C.

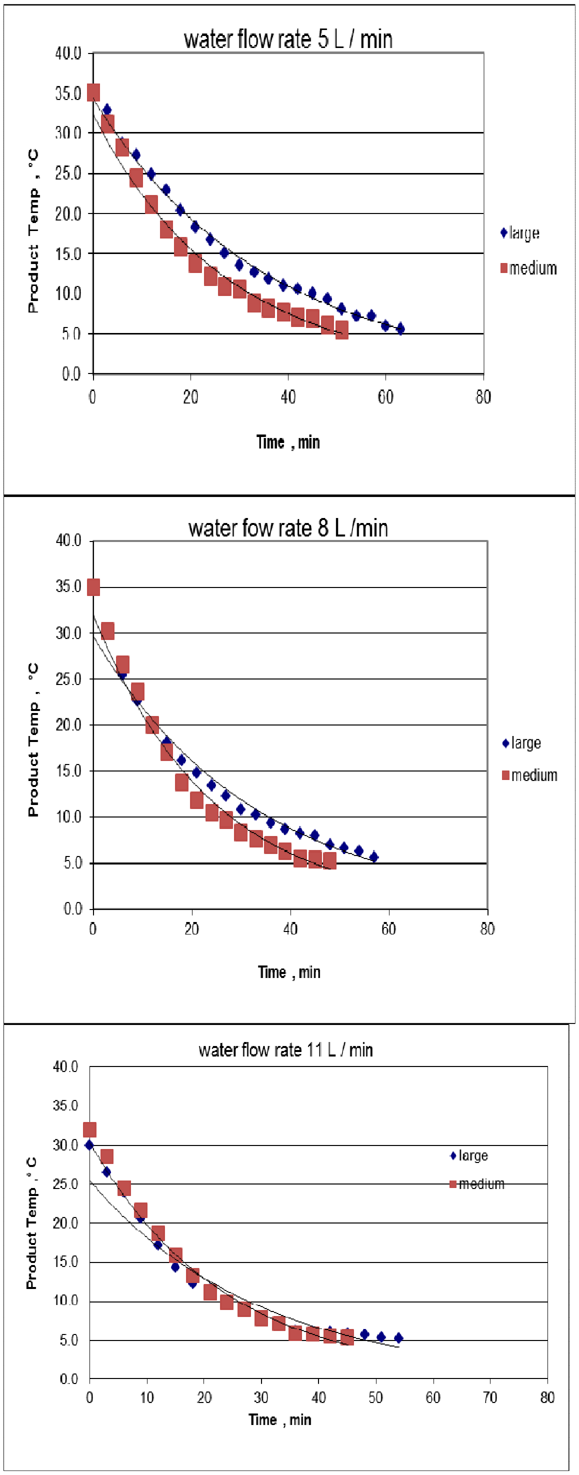


Fig. 4. Average core temperature of apple fruits as related to cooling time for water cooling temperature of 5 °C.

The Cooling Coefficient (C) and Lag Factor (J):

Table (1) presents the values of lag factor (J), cooling coefficient(C) coefficient of determination (R^2), and standard error (S.E) for different volumes of apple fruits. As it can be seen from table (1) the cooling coefficient (C) ranged from 0.05 to 0.13 min $^{-1}$ and the lag factor (J) ranged from 0.99 to 1.57, the coefficient of determination (R^2) ranged from 0.90 to 0.99, the standard error (S.E) ranged from0.29 to 0.41. It can also be seen that, the values of cooling coefficient (C) increased with the increase of water flow rate. While, it was decreased with the increase of cooling water temperature and fruits volume. The constant lag factor (J) did not follow an obvious trend and it was ranged from 0.99 to 1.57. These results are in agreement with Ravi *et al*. (2008) and El-Kholy *et al*. (2010).

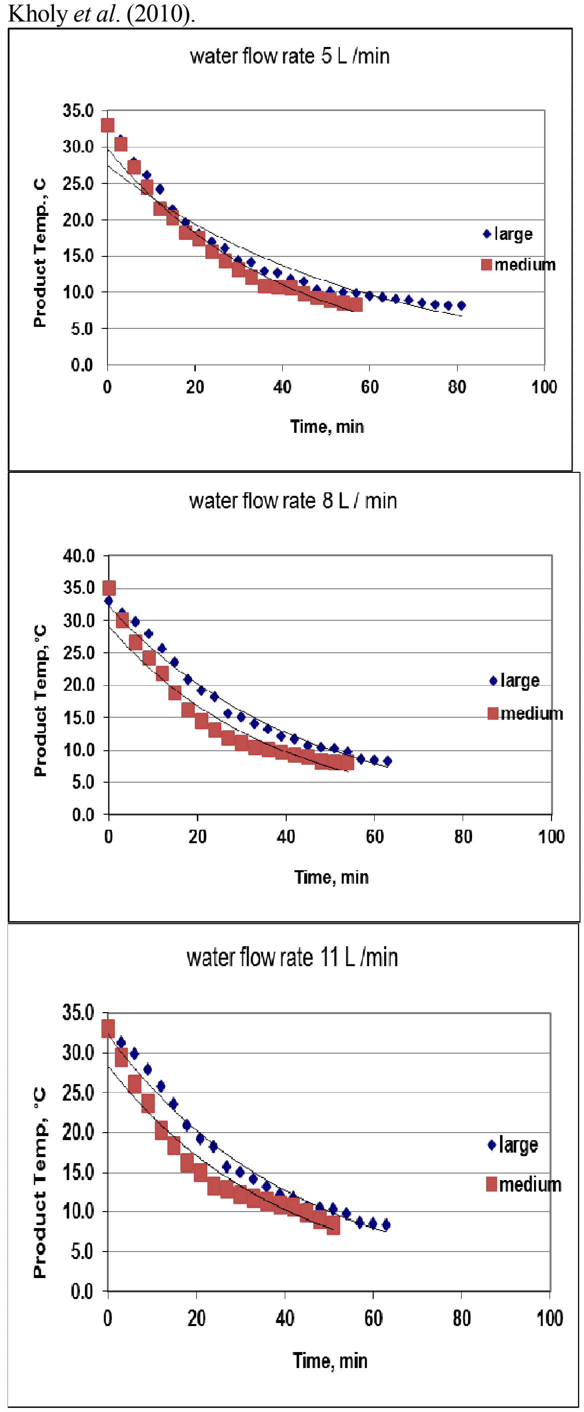


Fig. 5. Average core temperature of apple fruits as related to cooling time for water cooling temperature of 8 °C.

Table 1. The lag factor (J) and cooling coefficient (C) of apple fruits pre-cooled under different experimental variables.

Fruit volume	Water Temp,°C	Flow rate of water, L/ min											
		11				8				5			
		J	C min^{-1}	R^2	S.E	J	C min^{-1}	R^2	S.E	J	C min^{-1}	R^2	S.E
Large	3	1.2	0.081	0.99	0.34	0.99	0.068	0.91	0.29	1.45	0.062	0.92	0.37
	5	1.33	0.080	0.98	0.35	1.07	0.059	0.97	0.29	1.35	0.052	0.90	0.34
	8	1.57	0.064	0.92	0.38	1.27	0.052	0.98	0.33	1.36	0.051	0.96	0.34
Medium	3	1.49	0.13	0.96	0.41	1.49	0.1	0.92	0.39	1.37	0.09	0.94	0.36
	5	1.46	0.09	0.97	0.33	1.5	0.087	0.96	0.38	1.28	0.07	0.97	0.34
	8	1.15	0.085	0.92	0.31	1.47	0.083	0.95	0.36	1.37	0.05	0.96	0.35

Half and seven-eighth cooling times:

The half and seven-eighth cooling times of apple fruits decreased with the increase of water flow rate. While, they were increased with the increase of water cooling temperature and fruit volume. Table (2) illustrates the half and seven-eighth cooling times of apple fruits cooled at different levels of water temperature, water flow rate and fruits volume. The data presented in table (2), show that, for large volume apple fruits, as the cooling water temperature decreased from 8 to 3°C the half cooling time decreased from 17.22 to 10.81, 18.60 to 10.97 and 19.78 to 15.61 min at water flow rates of 11, 8 and 5 L / min, respectively. The corresponding values for medium volume fruits decreased from 10.41 to 8.43, 12.99 to 10.91 and 14.29 to 11.23 min at water flow rates of 11, 8 and 5 L / min, respectively. Meanwhile, for large volume fruits, the reduction of seven- eighth cooling time at similar levels of cooling water temperature were from 38.95 to 27.92, 46.32 to 33.33 and 47.17 to 35.99 min at water flow rates of 11, 8 and 5 L / min , respectively. For the medium volume fruits, the seven eighth cooling time decreased from 27.74 to 19.09, 29.70 to 24.78 and 34.01to 26.64 min at water flow rates of 11, 8, and 5 L / min, respectively.

Table 2. Values of half and seven- eighth cooling times of apple fruits.

fruit volume	Water temp., °C	Flow rate of water, L / min					
		11		8		5	
		H, min*	S, min**	H, min*	S, min**	H, min*	S, min**
large	3	10.81	27.92	10.97	33.33	15.61	35.99
	5	12.21	29.54	15.29	43.02	19.15	45.91
	8	17.22	38.95	18.60	46.32	19.78	47.17
medium	3	8.43	19.09	10.91	24.78	11.23	26.64
	5	9.73	25.13	12.21	27.61	13.43	33.23
	8	10.41	27.74	12.99	29.70	14.29	34.10

*** H= Half cooling time. ** S= Seven eighth cooling time.**

Refrigeration Load:

The average estimated refrigeration capacity (P) and total refrigeration load (P_t) of the developed pre-cooling unit at different water flow rates, water temperatures and volumes of apple fruits are tabulated in table (3). Considering the average mass of fruits equal to 850 and 500 g for large and medium volume fruits, respectively. Both, the refrigeration capacity and total refrigeration load decreased with the increase of cooling water temperature and decrease of water flow rate and fruit volume.

Effect of cooling water temperature:

From the obtained data it was clear that, for the large volume fruits, decreasing the cooling water temperature from 8 to 3 °C tends to increase the refrigeration capacity from 41.88 to 67.8, 38.04 to 60.72 and 34.62 to 56.22 Watt at water flow rates of 11, 8 and 5 L/ min, respectively. The corresponding values for the medium volume fruits increased from 38.04 to 62.34, 34.92 to 48.06 and 28.14 to 44.7 Watt, at water flow rates of 11, 8 and 5 L/ min, respectively.

On the other hand, it can be seen that decreasing the cooling water temperature from 8 to 3 °C increased the refrigeration load (P_t) from 52.38 to 84.72, 47.58 to 75.9 and 43.26 to 70.26 Watt at water flow rate 11, 8 and 5 L / min, respectively. The corresponding values for the medium volume fruits increased from 47.58 to 77.94, 43.62 to 60.06 and 35.22 to 55.86 Watt at water flow rate 11, 8 and 5 L / min, respectively.

Effect of water flow rate:

The effect of water flow rate on refrigeration capacity and total refrigeration load showed that, for large volume fruits increasing the water flow rate from 5 to11 L / min tends to increase the refrigeration capacity from 56.22 to 67.8, 42.66 to 55.26 and 34.62 to 41.88 Watt at cooling water temperature of 3, 5 and 8 °C, respectively. The corresponding values for the medium volume fruit were 44.7 to 62.34, 34.62 to 45.36 and 28.14 to 38.04 Watt at cooling water temperature of 3, 5 and 8 °C, respectively.

Also, the results show that by increasing the water flow rate from 5 to 11 L / min the total refrigeration load of large volume fruits increased from 70.26 to 84.72, 53.34 to 69.06 and 43.26 to 52.38 Watt at cooling water temperature of 3, 5 and 8 °C, respectively. The corresponding values for the medium volume fruit were 55.86 to 77.94, 43.32 to 56.7 and 35.22 to 47.58 Watt at cooling water temperature of 3, 5 and 8 °C, respectively.

Table 3. The initial fruits temperature (Ti), estimated refrigeration capacity (P) and total refrigeration load (Pt) for apple fruits.

Fruit volume	Water temp, °C	Flow rate of water, L / min								
		11			8			5		
		Ti, °C	P, W	Pt, W	Ti, °C	P, W	Pt, W	Ti, °C	P, W	Pt, W
Large	3	32	67.8	84.72	34	60.72	75.9	34	56.22	70.26
	5	32	55.26	69.06	35	45.48	56.88	35	42.66	53.34
	8	33	41.88	52.38	35	38.04	47.58	33	34.62	43.26
Medium	3	34	62.34	77.94	34	48.06	60.06	34	44.7	55.86
	5	32	45.36	56.7	35	41.7	52.14	35	34.62	43.32
	8	33	38.04	47.58	35	34.92	43.62	33	28.14	35.22

Quality Evaluation Tests during Storage Process:

The quality evaluation tests of the stored pre-cooled and non pre-cooled fruits were conducted for the fruits as much as it was physically not deteriorated. The period of tests for the pre-cooled fruits ranged from 18 - 21 days while, it was ranged from 12 – 15 days for the non pre-cooled fruits depending upon fruits volume.

Weight loss of apple fruits during storage process:

A weight loss occurs in fruits due to respiration and by moisture transpiration due to the potential loss in its moisture content. As shown in table (4) as the cooled storage period elongated to 18 and 21 days, weight loss percentages of 3.6% and 3.1% was occurred for the large and medium volume pre-cooled samples, respectively. While the corresponding values for the non pre-cooled samples were 3.8% and 3.6% after 12 and 15 days respectively. These results are in agreement with Lidster (1990)

Fruit firmness:

The firmness of apple fruits gradually decreased with the increasing of storage time in cooled storage method. As shown in table (4), when the cooled storage period was elongated to 18 and 21 days the pre-cooled fruit firmness decreased from 7.3 to 3.5 Kg/cm^2 and from 7.7 to 3.14 Kg/cm^2 for large and medium fruit volumes, respectively. While the corresponding values for the non pre-cooled samples decreased from 7.13 to 3.1 Kg/cm^2 and from 6.73 to 3.4 Kg/cm^2 after 12 and 15 days of storage, respectively. These results are in agreement with Lidster (1990).

Sugar content:

The total sugar of apple fruits decreased with increasing of storage time. From table (4) as the cooled storage period for the pre-cooled samples was elongated to 18 and 21 days, the total sugar content decreased from 12.36 to 6.6% and from 12.9 to 7.1% for large and medium fruit volumes, respectively. The corresponding values for the non pre-cooled samples were decreased from 11.92 to 6.72% and from 12.75 to 6.8 % after 12 and 15 days, respectively. These results are in agreement with Esther *et al*. (2016)

Total soluble solids:

As shown in table (4) the total soluble solids increased as the storage period was elongated. When the cooled storage period was elongated to 18 and 21 days the total soluble solids of pre-cooled fruits increased from 11.19 to 13.35% and from 11.31 to 13.23% for large and medium fruit volumes, respectively. While the corresponding values for the non pre-cooled samples increased from 11.08 to 13.1% and from 11.28 to 13.4% after 12 and 15 days of storage, respectively.

Table 4. Effect of pre-cooling process of apple fruits on fruit weight loss, firmness, total sugar and total soluble solids for cooled storage method.

parameters	treatments	fruits volume	storage period, day							
			0	3	6	9	12	15	18	21
Weight, g	pre-cooled	large	188.56	188.27	187.5	186.76	185.35	183.42	181.71	-
		Weight losses,%	0	0.15	0.56	0.95	1.7	2.73	3.6	-
		medium	120.52	120.35	119.9	119.65	119.17	118.52	117.91	116.8
		Weight losses,%	0	0.14	0.51	0.72	1.12	1.66	2.17	3.1
	non pre-cooled	large	189.14	187.6	185.93	183.62	181.3	-	-	-
		Weight losses,%	0	0.51	1.39	2.62	3.8	-	-	-
		medium	120.17	119.95	119.32	118.46	117.51	116.23	-	-
		Weight losses,%	0	0.47	0.99	1.71	2.5	3.6	-	-
firmness, kg / cm2	pre-cooled	large	7.3	7	6.5	5.9	5.2	4.6	3.5	-
		medium	7.7	7.4	7	6.58	5.82	5.34	4.2	3.14
	non pre-cooled	large	7.13	6.26	5.4	4.53	3.1	-	-	-
		medium	6.73	6.4	5.9	4.7	4	3.4	-	-
Sugar content, %	pre-cooled	large	12.36	11.8	11.1	10.57	9.2	8.15	6.6	-
		medium	12.9	12.3	11.9	11.2	10.32	9.1	8.58	7.1
	non pre-cooled	large	11.92	10.82	9.65	8.1	6.72	-	-	-
		medium	12.75	11.25	10.17	8.7	7.75	6.8	-	-
T.S.S, %	pre-cooled	large	11.19	11.3	11.7	12.17	12.63	12.92	13.35	-
		medium	11.31	11.5	11.8	12.1	12.35	12.65	12.8	13.23
	non pre-cooled	large	11.08	11.7	12.3	12.6	13.1	-	-	-
		medium	11.28	11.6	12.1	12.48	12.8	13.4	-	-

CONCLUSION

1- The values of cooling coefficient (C) increased with the increase of water flow rate, decrease of fruit volume and decrease of cooling water temperature.
2- The half and seven-eighth cooling times of apple fruits decreased with the increase of water flow rate. While, they were increased with the increase of cooling water temperature and increase of fruit volume.
3- Both, the total refrigeration load (P_t) and the refrigeration capacity decreased with the increase of cooling water temperature and decrease of water flow rate and fruit volume.
4- Lower moisture loss, higher fruit firmness, higher total sugar and lower total soluble solids were observed for the pre-cooled samples in comparison with the non pre-cooled samples.

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التبريد المبدئى والتخزين المؤقت لثمار التفاح

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تم دراسة تأثير عملية التبريد المبدئى لفاكهة التفاح باستخدام وحدة صغيرة متنقلة على بعض خصائص الجودة للتفاح أثناء عملية التخزين المؤقت للثمار والتى اشتملت على الوزن المفقود ودرجة الليونة ونسبة السكريات ونسبة المواد الصلبة الذائبة وذلك تحت ظروف التخزين المبرد عند درجة حرارة ٣°م . وقد تمت التجارب بدراسة العوامل المؤثرة على عملية التبريد المبدئى للتفاح وذلك تحت ظروف التشغيل المختلفة للوحدة والتى اشتملت على مستويات مختلفة لدرجة حرارة مياه التبريد ومعدل تدفق المياه وذلك لكل من الثمار المتوسطة والكبيرة الحجم. واظهرت النتائج الخاصة بعملية التبريد المبدئى للتفاح زيادة معدل التبريد لكل من الثمار المتوسطة والكبيرة الحجم بانخفاض درجة حرارة مياه التبريد وزيادة معدل تدفق المياه. كما اظهرت النتائج ان سعة التبريد وحمل التبريد الكلى ازدادت بزيادة معدل تدفق ماء التبريد وحجم الثمار بينما انخفضت بزيادة درجة حرارة مياه التبريد. اظهرت ايضا نتائج عملية التخزين للثمار المبردة انخفاض الوزن المفقود وانخفاض نسبة المواد الصلبة الذائبة وزيادة درجة الليونة وزيادة نسبة السكريات للثمار المبردة مبدئيا مقارنة بالثمار الغير مبردة خلال فترة التخزين المؤقت للثمار.