Annals of R.S.C.B., ISSN:1583-6258, Vol. 25, Issue 5, 2021, Pages. 435-445
Received 15 April 2021; Accepted 05 May 2021.

Experimental Investigation on the Rate of Cooling and Hardness during Artificial Ripening of Pineapple Fruits

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Abstract
The present experiments were conducted to determine the kinetics of cooling rates (with respect to time) and firmness changes of pineapple fruits during un-steady state cooling before ripening the fruits. Pineapple fruits were cooled down from about 23.5^0C to 5.3^0C to enable them suitable for the pre-cooling chamber. 1.0 Metric Ton of pineapple placed in perforated plastic crates was cooled first to the desired optimum temperature of the ripening. Out of this, randomly selected 15 kg of pineapple fruits were taken for the experimental investigations. The cooling process during un-steady state is fitted to three mathematical models, viz. linear, exponential, polynomial equations. Polynomial second-order equation is found for the best fit between experimental and predicted values with R^2 value of 0.997. The firmness also changes during the un-steady state it can be measured with penetrometer. the highest correlation coefficients were found from a polynomial second-order equation with R^2 of 0.985. The experimental readings show that the consumable pineapple fruit firmness is 2.4 kg/cm^2. These artificial ripening of pineapple fruits gives good structure and color and the data collected could be useful for the design of higher capacity fruit cooling equipment and also for preserving fruits for a longer period.

Keywords: Pineapple fruits, ripening, cooling, mathematical modeling, pre-cooling, artificial ripening.

1. Introduction

Pineapple fruit is a rich source of vitamin C and is an effective immunity booster. When calcium carbide (CaC2), which is a carcinogenic substance, is in contact with the moisture, it produces acetylene gas. It is widely used by farmers for the ripening of fruits like banana, mango and pineapple. Most of the fruits produce ethylene gas that starts the ripening process but by using the calcium carbide some health issues do occur. This harmful substance is banned by the Government of India for using it as a ripening substance. Also, during the transportation in the un-steady state, over-ripening of fruits could be leading to spoilage and wastage of fruits.

To overcome this and to avoid the excess ripening and to preserve pineapple fruits for a longer period, refrigeration system is introduced. The process which improves the performance of a unit by reducing temperature and Rapid removal of field heat is known as pre-cooling. It can be achieved by several techniques such as hydro cooling, forced air cooling, room cooling, etc. Refrigeration system consists of a compressor, condenser, expansion device and cooling unit (Evaporator). This system pre-cools the fruits to obtain the desired temperature.

The Hardness/firmness of fruit also plays an important role in the ripening of fruits. Due to climate change fruits undergo a number of changes during fruit ripening. These changes begin in an inner part of the fruit. But before the ripening process starts, the fruits are brought to the place of marketing through non-refrigerated trucks commercially. The handling of pineapple fruits in refrigerated containers is not yet practiced by majority of farmers or traders in India.

The aim of the present study is to investigate the cooling process of pineapple and ripening in an artificial fruit ripening chamber and also check the hardness (or) firmness of fruits. The pineapple was cooled from ambient temperature 20-25^{0}C to 5-10^{0}C in an insulated chamber in the city of Vijayawada. The rate of cooling is determined in a forced-air cooling chamber (pre-cooling chamber) and results are presented. The Rate of cooling with respect to time is modeled using three mathematical equations. The objectives of the present experiments are to:

1. Investigate the temperature profiles of pineapple pulp during the pre-cooling stage for artificial ripening of pineapple fruits.
2. The rate of cooling during an un-steady state of pre-cooling.
3. To find the hardness (or) consumable firmness of pineapple fruit with the help of a penetrometer at different temperatures and understand the change with respect to time.
4. Fit the experimental values with predicted values using the mathematical models (kinetics of temperature change with respect to time).

2. Literature Overview

Narasimha Rao et al. (1992, 1993a and 1993b) have studied the aspects of spherical fruits and they have used hydra air cooling for the pre-cooling process. They are mainly used both air and water spray for experimental setup to produce the pre-cooling. These studies help to develop artificial ripening of fruits and the importance of pre-cooling chambers [1-3].

Ramesh Babu et al. (2018 & 2019) extensively investigated the handling of fruit preservation and reported that the process of ripening mango and banana harms the consumer if they are using calcium carbide of the ripening process. To prevent these good practices from ripening fruits their recommended ethylene-based ripening system for safe and healthy fruits availability [4-5].

Eyarki Nambi et al. (2016 & 2017) observed the texture and changes occurring during the ripening process and he is introduced the hierarchical method and ripening period of mango are classifying viz., unripe, early ripe, partially ripe, ripe, and over ripe based on this stages color grade sheets are developed. And drastic information observed that when apples placed with banana ripened within 4 days while artificial agent takes 5 days to ripe [6-7].

Diego Alberto Castellanos et al. (2014) study that multidisciplinary groups of chemists, biologists, and engineers are necessary to develop more general and complex models for the description of quality properties [8]. (Kader, 2002; Thomson et al., 2002) reported that some products such as avocados, bananas, grapes, lemons, limes, papayas, and tomatoes do not tolerate low temperatures, and their optimum storage temperature is approximately 10°C [9-10].

Chen Huan et al. (2020) studies the Effect of 1-methyl cyclopropane treatment on quality, volatile production, and ethanol metabolism in kiwifruit during storage at room temperature during his studies they came to know that, 0.5 μL L-1 of 1-MCP might be an optimal concentration for improving post-harvest quality. In the present study, kiwifruit decay incidence significantly declined in 1-MCP treated groups in the company with the decrease of respiration rate during storage [11].

Fernando Mendoza et al. (2014) study the considerable work on a non-destructive method for the

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measurement of apple mealiness in the past year and also used acoustic detection response technique is based on capturing the sound signal of fruits and when it vibrates in response to light and also present work is carried out to evaluate the feasibility of the acoustic signal of rolling apples in an inclined plate to discriminate mealy and healthy apples. Finally, the apple mealiness is detected in a non-destructive way. The analysis indicates 85.5% accuracy by using this method [12].

W. Gruyters et al. (2017) performed numerical evaluation of adaptive on-off cooling strategies for energy savings during long-term storage of apples. This paper presents a transient CFD model to evaluate automatic on-off cooling control based on different temperature differentials (0.4, 0.5 and 0.7 °C around a set point). We observe after harvest; the apple fruit are often stored at low temperature in combination with controlled atmosphere conditions. Although no effects on apple firmness of the larger differentials were observed since lowering the evaporator outlet air temperature to lower values than 0°C could reduce the cooling times and thus also the energy consumption [13].

Antoni Femenia et al. (2004) studies mathematical modeling of the drying curves of kiwi fruits: influence of the ripening stage. A finite difference method has been proposed to simulate the drying kinetics at different temperatures. Drying curves of ripe kiwis exhibited only one diffusional period, whereas two different diffusional periods could be observed on the drying curves of green and half-ripe kiwi fruit [14].

Ethylene is a naturally synthesized hormone in plants and it helps in the ripening of fruit. (Watkins, 2003); study that physiologically active at concentrations of 0.1 ppm and below. Non-climacteric fruits generate a small amount of ethylene as a product of their metabolic processes. The effect of postharvest storage conditions on physiological processes and biochemical related to respiration and transpiration and on quality property changes. Moreover, equations developed by many authors that describe the changes in these processes and properties according to storage conditions are reported. Moreover, it is necessary that these models also consider other quality indicators such as aroma and taste. [15]

Narasimha Rao et al. (2020a and 2020b) reported the Mathematical modeling of Pre-cooling kinetic Rates during artificial ripening of Banana and Mango fruits under refrigerated conditions. They concluded that polynomial regression equations shown best fit between predicted and experimental values with above 0.95 regression coefficients [16-17]. Several Researchers reported on the preservation of fruits and vegetables. Several physic-chemical changes during fruit ripening were reported in the literature [18-22]. Low oxygen benefits along with low temperature for apple fruit preservation have been reported. Recommendations for low oxygen safety needs were reported [23].

3. Material and Methods

The ripening process of pineapple needs proper temperature, RH, and ethylene level management. The proper airflow, proper temperature during un-steady state and steady-state are ensured using electronically controlled refrigeration system. The temperature sensors to monitor and control apart from the data logging system and also check the hardness (or) firmness of pineapple fruits with help of the penetrometer.

To determine the firmness of pineapple fruits and the cooling rates, the arrangement is made with help of the temperature sensor carefully inserted in the pulp of pineapple and record the data continuously from chamber sealing, the time required to achieve the steady-state temperature. The technical details of the instruments are used given below:

3.1 Data logger:

Monitor the precooling process with the help of a temperature data logger: the model of the temperature data logger is RC-4, Make Eli-Tech, United Kingdom. The data logger has a temperature range from -40°C to

+80°C. The logger recording temperature interval, which can be set from 10 seconds to 24 hours range. The data logger can store 16000 data points. It connects the probe to measure the temperature of the pulp. The probe is inserted into the fruit up to the center (perpendicular to the diameter). The instrument is shown in Figure 1.

3.2 Fruit penetrometer:

Penetrometer measures the firmness/hardness of fruit. Penetrometers are ideal for determining the best time, to harvest the fruit or to test its progress of maturity. The fruit texture analyses monitoring the hardness/firmness of pineapple fruit process by using a fruit penetrometer. A fruit penetrometer is used of Model RC-4, GY series fruit penetrometer with 4 models: -GY-1, GY-2, GY-3, and GY-4, which are special for inspecting to know the hardness of the different fruits. Specially GY-3 mainly consists of two probes 8 mm and 11 mm, capacity for 12 kg/cm^2 (d = 0.1) to 24 kg/cm^2 (d=0.2). Among these two 11mm probe is used for this experiment. The probe is inserted into the fruit up to the center (perpendicular to the diameter). The instrument is shown in Figure 2.

3.3 Monitoring the room air temperature:

The digital thermometer is placed at the return air of the cooling unit inside the ripening chamber which records the return air temperature, which is the temperature of the air that picked the heat from the pineapple fruits and going to enter the cooling unit for lowering the temperature and to be blown again on to the fruit crates. This instrument has been supplied by the supplier of the equipment, refrigeration unit of the ripening chamber.

3.4 Fruits:

Pineapple of green color of uniform size is placed in 1.0 Metric tons, standard perforated plastic crate of Nilkamal make. Stacking of crates is done up to 5 stacks high leaving 2 feet of space between top layers of a top crate and cooling unit height to allow free flow of air from the cooling unit fans. A stacking pattern is made such that there is no obstruction for the return of air from the fruit crates to the cooling coil. Pineapple sourced from Bidhannagar zone of Siliguri is the biggest pineapple developing region in north Bengal are properly packed in 1.0Metric tons perforated plastic crates in a commercial ripening facility at Vijayawada was used for conducting the experiment.

About 1.0 Metric tons of pineapples were loaded into the ripening chamber at an initial pulp temperature of 25oC. After pre-cooling temperature out of which 15kgs of pineapple fruits are randomly selected for its observation. Crates were uniformly loaded and placed in the chamber floor with a maximum stack height of seven crates and leaving sufficient space for cool air circulation on the top of the top most crates. Two temperature sensing probes are set in the cold room one to measure the return air temperature near the evaporator and the other one is inserted in the middle fruit of the middle crate of the fourth row from the evaporator. The hardness/firmness of pineapple fruit is continuously records with the help of a penetrometer of 11mm probe and another probe is attached to a data logger, which records the temperature continuously.

3.5 Selection of temperature and Hardness (or) firmness levels:

The ripening temperature and firmness levels were decided as per the recommendations of Ramesh Babu et al. (2019) and Narasimha Rao et al. (1992) [1 and 5].

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Table 1. Flow chart for ripening process and determine the hardness of pineapple fruits

Pineapples are placed in plastic crates 1.0 Metric tons out of which 15kg fruits are taken for observation.

↓

Crates are stacked in the ripening chamber of temperature 3.7^0C

↓

Now check the hardness of fruit with the help of penetrometer and data logger temp recorder

↓

Now cooling unit is switched on

↓

Set the desired temperature

↓

Sensor of data logger is inserted in the fruit at the middle crate to record fruit pulp temperature

↓

Chamber door is closed hermetically

↓

Once set temp is achieved from 23.5 to 5.3°C in the pre-cooling chamber

↓

After 360 minutes pre-cooling chamber door is opened to release of excess co_2

↓

After 360 minutes further, the door is opened for release of excess co_2

↓

After achieving desired color, the fruit crates are removed from the chamber

↓

Now observe the hardness of the fruit with help of the penetrometer

↓

Check the hardness of pineapple fruits for every 4 hours of each time interval, the hardness/firmness of fruit is slowly changed

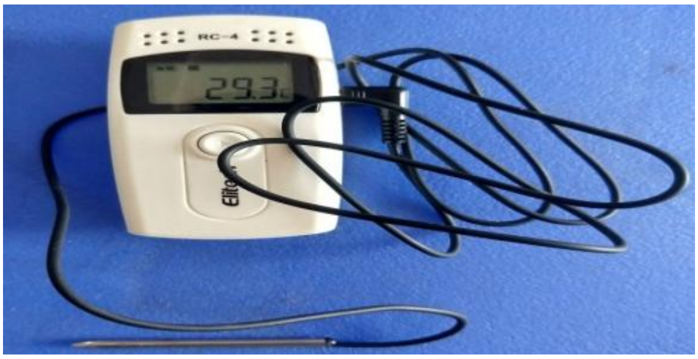

Figure 1: Elitech RC-4 Temperature Data Logger with Probe

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Figure 2: Fruit Penetrometer RC-4 with Probes

Figure 3: Monitoring the temperature with data logger and firmness with a penetrometer

4. Results and Discussion

Figure 4 shows the cooling rate of 15 kgs of pineapple fruits are taken from 1.0 Metric ton, placed in a domestic refrigerator at Vijayawada cooling chambers.

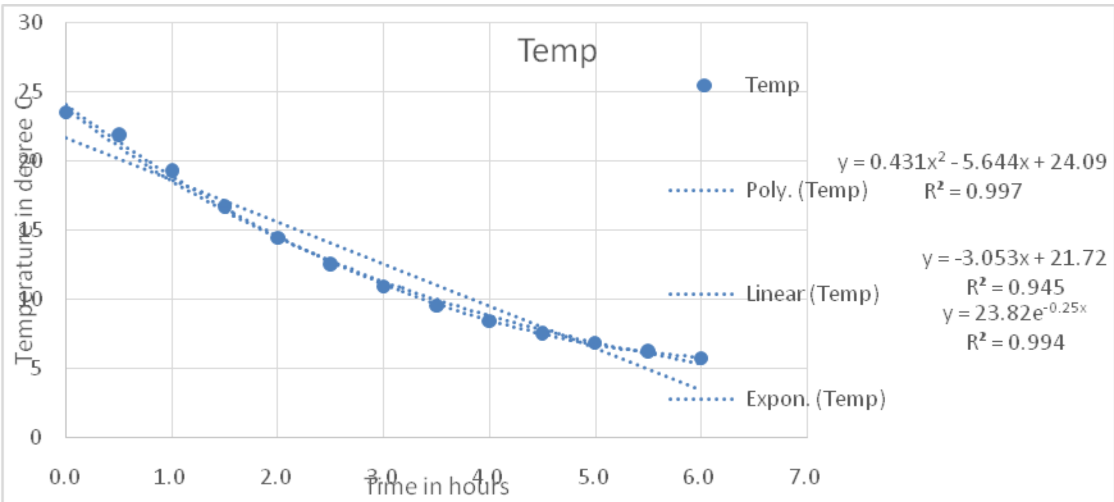

Figure 4. X-axis indicates the time in hours and the y-axis indicates various temperature profiles of pineapple fruits.

The Cooling rates are calculated from the experiment, a small number of pineapple fruits (15 kg) has been

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taken for the observation in a domestic refrigerator, the probe is inserted in the pulp at the center of the pineapple bunch. The temperature has been decreased from 23.5^{0}C to 5.3^{0}C in 360 minutes. Data logging report is plotted in MS excel for further processing and determining the rate of cooling. As expected the time required to reach the set ripening temperature (which is the steady state temperature also) found to be higher for higher quantities of pineapples.

Two distinct regions can be seen in the curve. One region is the unsteady state, till the temperature reaches the set value and the second region after reaching set point temperature. The rate of cooling is modeled with three mathematical equations, viz. linear, exponential and polynomial second order. A polynomial equation of second-order was found to be the best fit with R square value of 0.997 between the experimental and the predicted values.

This experiment has been carried out to establish the rate of cooling for small quantity and also to verify the use of a new data logger procured for the purpose of experiments and also to know the firmness/hardness of fruit with the help of new fruit penetrometer it is found that average curve of firmness changes in pineapple fruits.

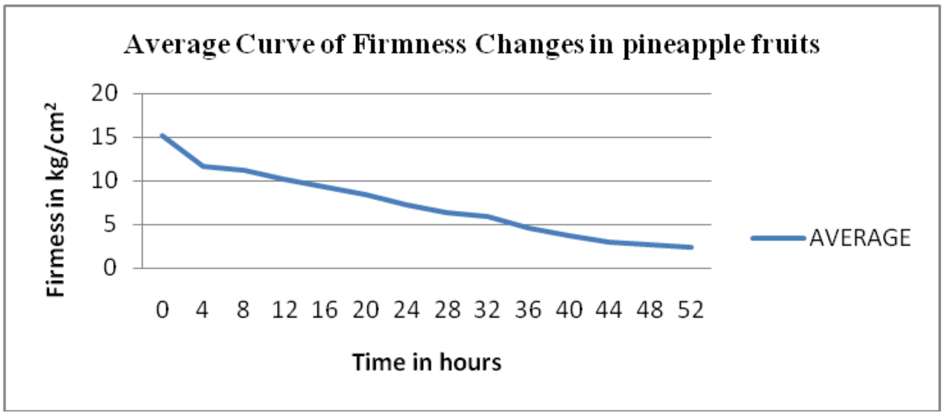

Figure 5. Average curve of firmness changes in pineapple fruits (X-axis indicates the time in hours and the y-axis indicates various firmness profiles of pineapple fruits)

After removing 17 to 18^{0}C to avoid excess ripening hardness of fruit is to be observed for every four hours of time interval that has to be found that the average curve of firmness of pineapple fruits is changing from 15.1 kg/cm^2 to 2.4 kg/cm^2. From figure 5 these investigations known that firmness changes in the pineapple fruits.

After removed from the chamber the firmness has to be checked with the help of penetrometer for every four hours of time interval then fruit penetrometer report is plotted in MS excel for further processing and determining the rate of cooling and firmness of pineapple fruits, to be found that firmness changes of the pineapple fruits. And this is definitely expected to be more due to more sensible and latent heat from the fruits. Sensible heat is due to the fruit temperature and latent heat can be due to the moisture evaporation from the fruit apart from the respiration heat.

The pineapple fruits can be kept in good condition in the cool place without refrigeration system up to one week. The pineapple can be stored in between four and six weeks at 14°C to 20°C. But Pineapples are placed in Pre-cooling refrigeration system to survive for longer period. The experimental readings showed that the consumable pineapple hardness is 2.4 kg/cm^2.

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During ripening, important chemical changes occur inside a fruit. In fact, the properties of many biological products and their ability to be processed are largely determined by the ripening stage. Mathematical models for predicting the thermal properties often required for heat transfer calculations in the fit of experimental values with predicted values (kinetics of temperature change with respect to time).

The pineapple pulp/core temperature is continuously recorded during the pre-cooling and ripening process till 360 minutes approximately, which is shown in Figure 4. The initial temperature of pineapple was found to be 23.5^0C and the set temperature of 5.3^0C was achieved in six hours from loading. After observe the hardness of pineapple fruits for every 4hrs of time interval the hardness/firmness of fruit is slowly changed. The pre-cooling data during an unsteady state (till set temperature reached) has been analyzed further from the figure 6.

The firmness changes in pineapple during an un-steady state (till the fruits reach the set ripening temperature). The time to reach the consumable firmness set temperature is approximately 52 hours. The temperature profiles were subjected to the kinetic modeling with respect to time using three mathematical models, viz. linear, exponential, and second-order polynomial equations. The best fit between experimental and predicted values found to be with the polynomial equation with R square value of 0.985.

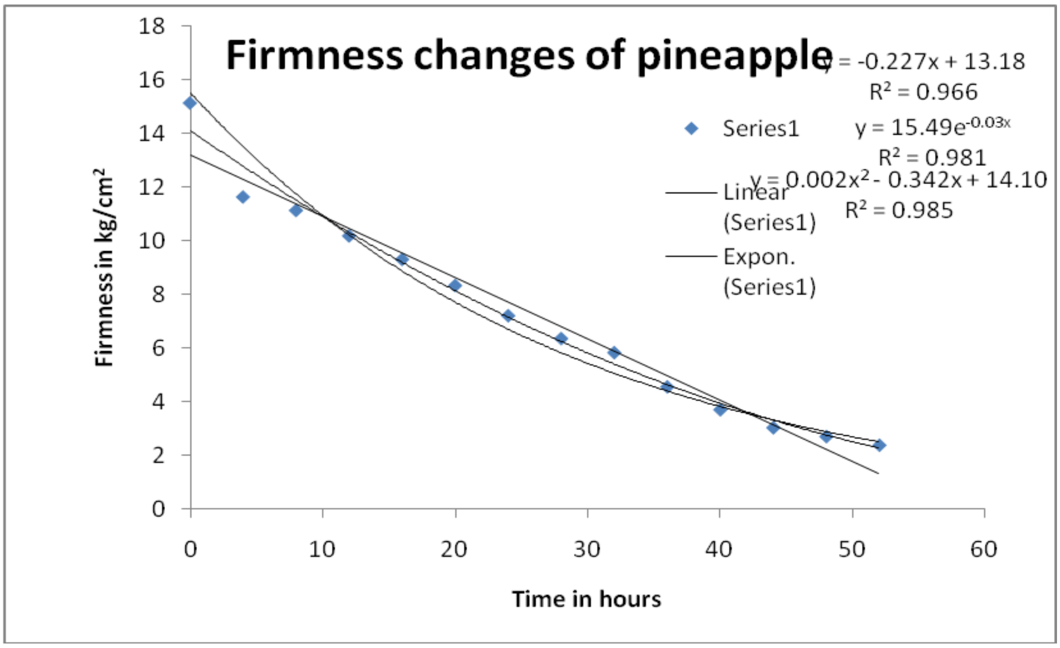

Figure 6. Firmness with time changes of the pineapple curves showing the fitting of mathematical models (Experimental data with the predicted data).

5. Conclusion

From the pineapple fruit cooling curve during pull-down conditions (in an un-steady state), it can be noticed that the fruit pulp temperature reached from an initial temperature of 23 to 5 ^{0}C in about 6 to 7 hours. This pre-cooling helps the proper ripening of pineapple fruits. Further the penetrometer and the data logger can be forced into the pineapple fruit to measure resistance to vertical penetration.

The kinetic rate of cooling with respect to time is mathematically modeled with Linear, Exponential and Polynomial equations. The correlation coefficients found were 0.994, 0.945, and 0.997 for linear, exponential, and polynomial equations.

The highest correlation coefficients were found with a polynomial second-order equation with R^2 of 0.997 between experimental and predicted values. The average value of firmness changing from 15.1 kg/cm^2 to 2.4 kg/cm^2.

Hence the consumable pineapple fruit firmness is 2.4 kg/cm^2. And also firmness changes in pineapple fruit of cooling with respect to time is mathematically modeled with Linear, Exponential and Polynomial equations. The correlation coefficients found were 0.966, 0.981 and 0.985. The highest correlation coefficients were found with a polynomial second-order equation with R^2 of 0.985 between experimental and predicted values.

These results can be useful for the design of refrigeration equipment with ripening systems to know the hardness/firmness of the fruit during the pre-cooling process. This knowledge helps investigators to preserve fruits for longer periods.

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