March-April 2020
ISSN: 0193-4120 Page No. 6872 - 6879

# Mathematical Modeling of Pre-Cooling Kinetic Rates during Artificial Ripening of Banana Fruits under Refrigerated Conditions

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***Abstract:***
The present study was carried out to determine the rate of cooling of banana during artificial ripening in an insulated and refrigerated ripening chamber. Banana fruits were cooled from about 29ºC to 19ºC to enable them suitable for ethylene ripening process. 100 pm of ethylene gas is used for ripening a quantity of 5.0 Metric Ton (MT) of banana. Cooling and ripening took about 3 days for uniform and good colored ripe fruits. The cooling process during un-steady state is fitted to three mathematical models, viz. linear, exponential, polynomial equations. Polynomial second order equation found with the best fit between experimental and predicted values with R2 value of 0.939. The data could be useful for design of higher capacity fruit cooling and ripening chambers.

***Keywords:*** *Banana fruit, Cooling, Ripening, Ethylene, Refrigeration, Rate of cooling*

## I. INTRODUCTION

Certain fruits like Mango, Banana, Papaya and citrus fruits (Oranges, Kinnow, Sweet lime, Lemon) need to be cooled to appropriate temperature for reducing the respiration rate and spoilage. Apart from cooling, the fruits need to be artificially ripened without using harmful chemicals like calcium carbide. Ethylene is a natural agent which can be used for ripening of fruits, which are harvested before the ripening start on the tree. The reason for harvesting fruits before ripening start is to enable them to transport for long distances. Otherwise these fruits may get spoiled during transportation.

Whenever fruits are harvested before start of actual ripening on tree, they will never ripen on their own. Here the artificial ripening comes into picture. Safe methods are available for artificial ripening of fruits.

The technology used consists of a ripening chamber made of Poly urethane foam (PUF) insulated chambers (of 60-100 mm thick sandwich panels), Refrigeration system connected to the insulated chamber with a suitable evaporator and cooling fans for uniform air circulation to remove the field heat from the fruits, An ethylene generator which generate 100 to 150 ppm of ethylene for triggering the ripening in the fruits.

Banana fruits in India are harvested at right maturity, but before the ripening process starts and brought to the place of marketing through non-refrigerated trucks commercially. The practice of handling banana in refrigerated containers is not yet practiced by majority of farmers or traders in India.

The aim of the present study was to investigate the cooling process of banana and ripening in an artificial fruit ripening chamber. Bananas were cooled from ambient temperature 28-30ºC to 19-

March-April 2020
ISSN: 0193-4120 Page No. 6872 - 6879

20ºC in an insulated chamber in the city of Vijayawada. The rate of cooling is determined in a forced air 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 were to:

1. Investigate the temperature profiles of mango pulp temperature during pre-cooling stage during artificial ripening of bananas
2. Model the rate of cooling during un-steady state of pre-cooling
3. Fit the experimental values with predicted values using the mathematical models (kinetics of temperature change with respect to time)

## II. Literature Overview

Need of pre-cooling and importance along with numerical modeling was done by Narasimha Rao et al. (1992, 1993a, 1993b). They have studied the pre-cooling aspects of spherical fruits and modeled the pre-cooling process. They have used hydrair cooling for pre-cooling process. They have used an experimental set up with both air and water spray to pre-cool the produce [1-3].

Ramesh Babu et al. (2019) reported about the design of refrigeration systems, ripening equipment and technology details suitable for banana and mango ripening. They also reported the insulation chamber dimensions, ethylene levels requirement for optimum ripening, benefits of ethylene compared to traditional non-permitted calcium carbide ripening [4].

Ramesh Babu et al. (2018) extensively investigated the handling of fruits and reported the incidence of surface damage during handling and loss of texture during storage. However they reported the firmness changes of apples during controlled atmosphere storage. Preserving the fruits in perforated plastic bins has been reported. The time taken for apples to pre-cool is 120 hours (fruit to reach temperature of 1ºC from an initial temperature of 25-30ºC) [5].

Sadashive Gowda et al. (1994) reported the pre-cooling process of spherical fruits using parametric modeling [6].

Bagnato et al. (2003) experimented on Cavendish banana; the control group were exposed to ethylene gas for 48 hours to induce fast ripening and then exposed to 1-MCP (methyl-cyclo-propene) of various concentrations for 24 to 72 hours. The exposure to 300 nLL-1 of 1-MCP showed improved shelf-life of the fruit from 3days for untreated to 6days for treated. Treating with high concentrations such as ≥30µLL-1 made the fruit externally and internally unacceptable to consume [7].

Robert E. Paul (1996) reported that finger drop during postharvest of Dwarf Brazilian Banana is more common phenomenon so, treating the control group with ethylene gas for 24hours at 25˚C significantly reduced finger drop. Ripening the fruit at 25˚C for 1 day and then at 17.5˚C reduced the finger drop to 10% [8].

Mahajan et al. (2010) reported that, initially bananas are exposed to ethylene gas (100 ppm) for 24 hours in ripening chamber. Second lot is treated with an aqueous ethphon solution of (250, 500 and 750 ppm) respectively each for 5 minutes. These bananas are closely packed and stored at a temperature (16 to 18˚C) and RH 90 to 95%. At a time period of 4 days, bananas turn into uniform color, desirable firmness, pleasant flavor, etc. achieved. The untreated bananas possess hard texture and poor color [9].

Surabhi Gandhi et al. (2016) reported the comparison between natural ripening agents like apple, pear, tomato and artificial ripening (calcium carbide) of banana. Ripening ability is examined by two different conditions paper bag and plastic container. Sensory evaluation is done by Hedonic Scoring. Data revealed that fruits kept in plastic container ripen fast compare to paper bags.

Drastic information observed that, apples placed with banana ripened within 4 days. Banana with artificial agent takes 5days to ripe. Apples can be successfully used for banana ripening, which prevents the unwanted chemical and health risks [10].

Slaughter (2009) Studied and reported the

March-April 2020
ISSN: 0193-4120 Page No. 6872 - 6879

management for the ripening of banana. The critical parameter that affects the shelf life of mango is temperature management. Because it results in fruit appearance, palatability and decay control about ripening of mangos. Mangos when treated at the outside temperature will result in decrease in quality and leads to injure the fruit. In order to minimize the water losses and shriveling of mangos, ripening process is carried out at the rate of ethylene gas at 100 ppm and RH 90 to 95% over a period of 24 hours [11].

Beyond this several methods are adopted to enhance the shelf life of mangos. In actual practice, method depends on availability or action of oxygen, carbon dioxide and ethylene during ripening process.

Nura et al. (2018) have experimented on the effects of using artificial ripening agent, Calcium Carbide (CaC2), on the ripening of banana fruit with different levels of CaC2. The fruit was exposed to CaC2 in two stages, first in airtight chamber at 34˚C for 48 hours and then fruit is transferred into jute bags and water is sprinkled to lower the temperature for 22 hours at 32˚C. With increase in calcium carbide concentration fruit lot showed increase in ash, moisture, lipid content and showed decrease in vitamin C, titritable acidity and pH [12].

Ram Deshmukh et al. (2020) reported the importance of sealed chambers for maintaining gas composition in fruit storage chambers. The insulation panels of the fruit pre-cooling, controlled atmosphere storage need to be gas tight, so that oxygen, carbon dioxide gas levels can be maintained without any leakage [13].

Ramesh Babu et al. (2019) reported the process of ripening of mango and banana without using harmful chemicals such as calcium carbide. They reported the consumer awareness on the bad practices and good practices on ripening of fruits. Their report recommended for wider dissemination of ethylene based ripening systems for safe and healthy fruits availability [14].

## III. Materials and Methods

Ripening process of banana needs proper temperature, RH and Ethylene level management. Proper air flow, temperature during un-steady state and steady state are ensured using electronically controlled refrigeration system, temperature sensors to monitor and control apart from data logging. To determine the cooling rates, arrangement is made with a temperature sensor carefully inserted in the pulp of banana and record the data continuously from chamber sealing time to the steady state temperature achievement. Technical details of instruments used are given below.

### 3.1 Data logger**:**

Monitoring the precooling process using a temperature data logger:

A temperature data logger is used - Model RC-4, Make: Eli-tech, United Kingdom. The data logger has a temperature range from -40°C to +80°C. The logger recording interval can be set from 10 seconds to 24 hours range. The logger has a capacity to store 16000 data points. It uses a probe to measure the temperature of the pulp. The probe is inserted into the fruit up to the centre (perpendicular to the diameter). The instrument is shown in Figure 1

### 3.2 Monitoring the room air temperature:

A 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 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.

### 3.3 Fruits:

Bananas of green colour of uniform size are placed in 20 kg standard perforated plastic crate of Nilkamal make. Stacking of crates is done up to 7 stacks high leaving 2 feet space between top layers of top crate and cooling unit height to allow free

March-April 2020
ISSN: 0193-4120 Page No. 6872 - 6879

flow of air from the cooling unit fans. Stacking pattern is made such that there is no obstruction for the return air from the fruit crates to the cooling coil.
Banana sourced from Nanded of Maharashtra are properly packed in 20 kg perforated plastic crates in a commercial ripening facility in Vijayawada was used for conducting the experiment.
About 250 crates (5MT) were loaded into the ripening chamber at an initial pulp temperature of $29^0$C. Crates were uniformly loaded and placed on the chamber floor with a maximum stack height of seven crates and leaving sufficient space for cool air circulation on the top of the topmost crate. Two temperature sensing probes are setup in the cold room one to measure the return air temperature near evaporator and the other one is inserted in the middle fruit of the middle crate of the fourth row from the evaporator. This probe is attached to a data logger, which records the temperature continuously.

3.4 Selection of temperature and Ethylene level:
The ripening temperature and ethylene levels were decided as per the recommendations of Ramesh Babu et al. (2019) and Mahajan et al. (2010) [4, 9].

3.5 Flow chart for ripening process:

Bananas are placed in plastic crates of 20kg each
↓
Crates are stacked in the ripening chamber floor
↓
Cooling unit is switched-on
↓
Desired temperature is set
↓
Sensor of data logger is inserted in the fruit in the middle crate to record fruit pulp temp.
↓
Chamber door is closed hermetically
↓

Once set temp is achieved, Ethylene is released @100 ppm into the chamber
↓
After 24 hours of ethylene injection, door is opened to release $CO_2$
↓
After every 24 hours further, the door is opened for release of excess $CO_2$
↓
After achieving desired color, the fruit crates are removed from the chamber
↓
In case of any delay expected in the marketing of banana, temperature is further lowered to

17 to $18^0$C to avoid excess ripening.

**Figure 1**: Temperature data logger

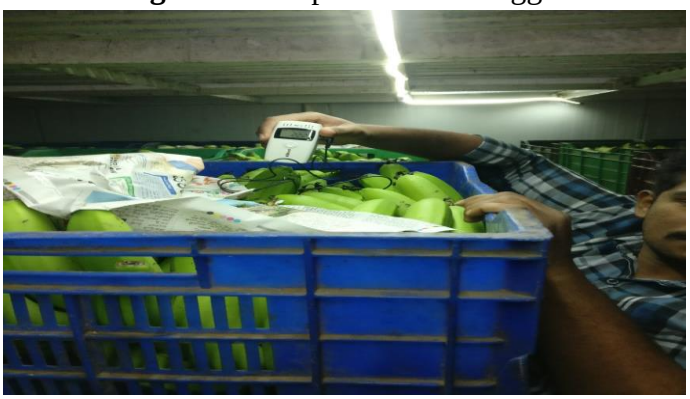
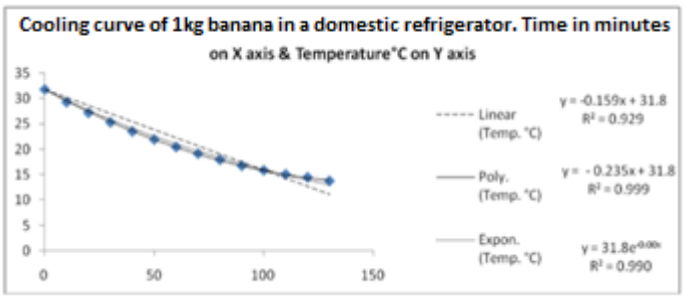


**Figure 2**: Inserting the temperature probe of data logger into the banana for data logging in the ripening chamber

## IV. Results and Discussion

Figure 3 shows the cooling rate of 1 kg banana placed in a domestic refrigerator




As a preliminary experiment for the purpose of understanding the cooling rate, a small quantity of banana (1 kg) has been placed in a domestic refrigerator and the probe is inserted in the pulp of the centre of the banana bunch. The temperature has been decreased from $31.8^o$C to $13.7^o$C in 130 minutes. The rate of cooling is modeled with three mathematical equations viz., linear, exponential and polynomial second order. Polynomial equation of second order found to be the best fit with R square

March-April 2020
ISSN: 0193-4120 Page No. 6872 - 6879

value of 0.999 between experimental and predicted values.

This experiment has been carried out to establish rate of cooling for small quantity and also to verify the use of new data logger procured for the purpose of experiments to be conducted with large quantity (5MT) in a commercial ripening chamber.

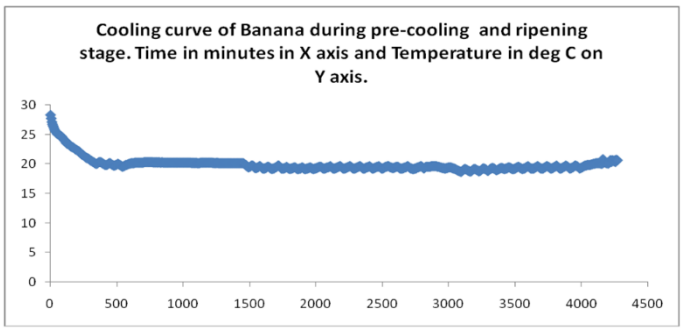



**Figure 4**: Temperature profile of 5MT banana in ripening chamber

The banana pulp/core temperature is continuously recorded during pre-cooling and ripening process till 72 hours (3 days) approximately, which is shown in Figure 4. The initial temperature of banana was found to be 28.3$^{o}$C. The optimum temperature of 20 $^{o}$C was achieved in six hours from loading. The pre-cooling data during un-steady state (till set temperature reached) has been analyzed further in Figure 4.

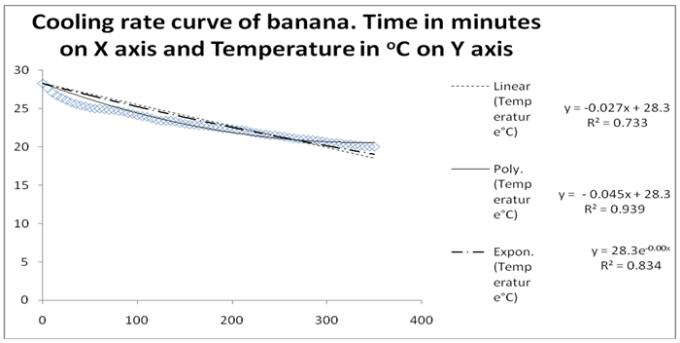



**Figure 5**: Cooling rate curve showing the fitting of mathematical models (Experimental data with the predicted data)

The cooling curve of banana during un-steady state (till the fruits reach the set ripening temperature) is shown in Figure 5. The time to reach the set temperature is approximately 350 minutes. 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 0.939.

## V. Conclusions

From the banana cooling curve during pull down condition (in unsteady state), it can be noticed that the fruit pulp temperature reached from an initial temperature of 29 to 19 in about 6 hours. This pre-cooling helps the proper ripening of banana fruits. The kinetic rate of cooling with respect to time is mathematically modeled with Linear, Exponential and Polynomial equations. The correlation coefficients found were 0.733, 0.834 and 0.939 for linear, exponential and polynomial equations. The highest correlation coefficients found with polynomial second order equation with R2 of 0.939 between experimental and predicted values. These results can be useful for design of refrigeration equipment and ripening systems. Further work can be carried with variable quantity of fruits to decide the timing for ethylene injection for ripening purpose.

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## VII. AUTHOR'S PROFILE:

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Dr K V Narasimha Rao is a senior Professor with 27 years experience in Academic, Consultancy and Industry and has been working with KLEF (Deemed to be University) since 2 September 2016. Dr Narasimha Rao was graduated in Mechanical Engineering from Regional Engineering College, Warangal in 1986 and went on to obtain Master's and Doctoral degrees from the Indian Institute of Science, Bangalore during 1990 and 1995 respectively in the field of Thermal Engineering. He worked for seven years (1995-2002) as Research Associate and Fellow, Industrial Energy Group at Tata Energy Research Institute (teri), Southern Regional Centre, Bangalore before moving into Academics, Research and Administration during 2002. Prior to joining KLEF, he worked at few Engineering Colleges as Principal/Director/Dean. Dr Rao has published 28 scientific papers (three in SCI Listed Journals, 24 Scopus indexed Journals and Chapter 10 in Recent Advances in Material Sciences, Lecture Notes on Multidisciplinary Industrial Engineering) and numerous technical reports for various National/International Agencies. He has filed 14 patents (six published).

Membership of Professional Bodies:

Dr Rao is a member of ASHRAE, ISCA, ISHMT, ISHRAE, ISTE, SAE & SESI and a Fellow of Institution of Engineers (India).

Scholarships & Awards:

- Recipient of 'National Merit Scholarship' during 1980-85 (6 Years).
- Recipient of 'Special Rank' in Mathematics Olympiad conducted by Andhra Pradesh Association of Mathematics Teachers (APAMT), Hyderabad, A. P. at Senior Level during 1980-81.

Areas of Specialization: Energy Auditing, Energy Conservation & Management, Heat Transfer, Refrigeration and Air-conditioning and Renewable Energy Sources.

Research Guidance: Has supervised 14 M. Tech. Students and presently guiding eight PhD Scholars and four M. Tech. Students.

Important Projects handled: Was the Team Leader for the Consultancy Assignment on Energy Efficiency Services-Phase-III (3 May–30 November 1998), for the Ministry

of Industry, His Majesty's Govt. of Nepal, Industrial Energy Management Component of the Power Sector Efficiency Project (PSEP) – IDA Credit No. 2347-NEP, World Bank. The activities included Demand Side Management (DSM), Furnace & Kiln and Boiler Efficiency studies, Co-generation Feasibility studies covering 65 major industries in Nepal. Trained 11 Nepalese Engineers as Certified Energy Auditors as part of the Consultancy Assignment. Dr Rao was involved in the field-testing of a number of Energy Saving Devices / Retrofits under the Energy Saving Demonstration Project, funded by GTZ, Germany. Dr Rao has developed and Demonstrated "Performance Contract for Industrial Energy Management" for Indian Scenario, sponsored by Canadian International Development Agency.

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Sasank Devarakonda is currently pursuing M. Tech. in Thermal Engineering at Department of Mechanical Engineering at Koneru Lakshmaiah Education Foundation, Vaddeswaram, Guntur and graduated in Mechanical Engineering from SRM Institute of Science and Technology, Chennai in the year 2016. His research interests are Thermal engineering, Pre-cooling of fruits, Ripening process using ethylene gas, etc.

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D. Ramesh Babu has over 24 years of experience in manufacturing, research, maintenance, consultancy and project management related to Refrigeration, food processing and controlled atmosphere. He was graduated in Mechanical Engineering from JNTU College of Engineering, Hyderabad in the year 2000 and obtained MBA in production and operations management from MDU,Rohtak. He also obtained his M. Tech. in Advanced Manufacturing from JNTU,Hyderabad. He has got expertise in refrigeration, fruit preservation and food processing. He is presently working as Assistant Professor in Mechanical Engineering at S R Engineering College, Warangal. He has four years of experience in refrigeration equipment manufacturing at Voltas Limited, seven years of experience in fruit preservation at Defence food research laboratory, DRDO-Mysore and worked for eight years at cold chain project of CONCOR before joining teaching.

He is a recipient of DRDO cash award in the year 2003. He was nominated by CONCOR for eight days visit to ISRAEL as part of cold chain project for preservation of apples in the year 2011. He has published 4 research papers in SCI indexed journal and 9 papers in SCOPUS indexed journals and 6 in ICI indexed journals. He also presented numerous papers at various International and national conferences. His paper got best paper award by the TJPRC for the paper on "The Design of Refrigeration, Thermal Insulation and Equipment for Healthy Ripening of Mango and Banana without Using Harmful Chemicals." published in IJMPERD. He has filed one patent in the year 2019. He is currently pursuing his PhD in Mech. Engg at KLEF, Vijayawada. He is a life member of Condition Monitoring Society of India and Graduate member of Institute of Engineers (India).