

# Thermal Diffusivity Measurement of Spherical Shaped Food Products under Forced Convection Cooling

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**ABSTRACT:** This paper presents the development of an experimental method for determining the thermal diffusivity variations with temperature of selected spherical shaped solid food products subjected to forced convection cooling. Experimental investigations were carried on the sample chosen (potato and brinjal), which is approximately of spherical geometry. The variation of temperature within the food product is measured at several locations from centre to skin, under forced convection environment using a deep freezer, maintained at  $-10^{\circ}\text{C}$ . This method uses one dimensional Fourier equation applied to regular shapes. For this, the experimental temperature data obtained from cylindrical and spherical shaped products during pre-cooling was utilised. Such temperature and thermal diffusivity profiles can be readily used with other information such as degradation rate etc. to evaluate thermal treatments based on cold air cooling methods for storage of perishable food products.

**KEYWORDS:** Spherical shaped, forced convection, thermal diffusivity, skin temperature, pre-cooling.

## I. INTRODUCTION

The important nutrition-health and economic values of both fresh fruits and vegetables are well recognized. They are the best carriers of vitamins, essential minerals, dietary fibres, and other bioactive substances. These relevant nutritional and health promoting effects improve the state of human welfare and reduce the risk of various diseases.

Fruits and vegetables are highly perishable products. Currently, up to 25 to 30% of the most perishable fruits and vegetables are lost during their journey through the agri-food chain due to spoilage, physiological decay, water loss, mechanical damage during harvesting, packaging and transportation etc. [1]. These losses have been estimated to be more than 40 to 50% in the tropics and subtropics. Losses also occur during shelf-life and food preparation in home and services. Post-harvest losses of fruits and vegetables are more serious in developing countries than those in developed countries [2]. Moreover, in many developing countries only a limited quantity of fruits and vegetable products are produced for local markets or for exportation due lack machinery and infrastructure. Reduction of the high wastage of fruits and vegetables entails various measures to be adopted to minimize these losses during harvesting, handling, storage, packaging and processing of fresh fruits and vegetables.

Preservation is usually defined as a method used to maintain an existing condition or to prevent damage likely to be brought about by chemical (oxidation), physical (temperature, light) or biological (microorganisms) factors. Preserving food, made it possible to have food available from harvest to the next year. The main function of preservation is thus to delay the spoiling of foodstuffs and to prevent any alterations in their taste or, in some cases, their appearance. This can be done in different ways, through processing methods including canning, dehydration (drying), smoking and freezing; the use of packaging; and the use of food additives such as antioxidants or other preservatives.

Traditional methods to determine the thermal diffusivity of agricultural products have been the Fourier equation for transient heat transfer. This equation is limited to homogenous, isotropic substances with nice shapes such as sphere, slabs, cylinders etc. Most published data on thermal diffusivity are based on calculating thermal diffusivity from the

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known values of thermal conductivity, density and specific heat. Direct measurement of thermal diffusivity is not very common. Albin et al. [3] obtained thermal diffusivity from non-linear regression analysis of temperature histories of mashed potatoes. Annamma and Rao [4] determined thermal diffusivity of fresh fish. Heldman [5] gives the infinite series solutions to the governing differential equation for the infinite slab, infinite cylinder and a sphere and showed how to apply these solutions to solve heating and cooling problems. Singh and Heldman [6] present the Fourier equation in one dimension and solved heating and cooling problems using temperature response charts for the well-defined shapes. Pan and Bhowmik [7] used the finite element method to predict the temperature distribution in individual mature green tomatoes during forced air cooling. The calculated results were within 1°C of the experimental results when cooling the tomatoes from 20 °C to 12 °C.

In the present work, experimental investigations have been carried out to obtain heat transfer behaviour of food products during pre-cooling in forced convection environment. The sample chosen are brinjal and potato. Temperature-time variation, within the food product, is measured at several locations from centre to skin, under natural and forced convection environment using a deep freezer maintained at -10°C and U-duct maintained at 5°C respectively. Time-Radius ratio curves are extrapolated to obtain skin temperature. Temperature-time variation at skin is then plotted for above sample for forced convection environment. Finally thermal diffusivity variations in terms of skin temperature are calculated and plotted using the experimental temperature data obtained from the products during cooling.

### II. MATERIALS AND METHODOLOGY

**AIR-BLAST COOLING DUCT:** Air blast cooling duct consist of:

- 1.06m × 0.6m × 0.4 m refrigerated bunkers made of 22 S.W.G galvanized iron sheet with a 0.4m diameter hole at the top and a 0.2m diameter hole at the bottom end.
- From the upper hole a tapered duct 0.45m long was joined and its other end with a 0.2 m diameter closed duct. The whole duct was insulated by about 3 cm thick glass wool and refrigerated bunker with 2.5cm thick thermos freeze pieces
- As shown in Fig. 1 Schematic diagram of air blast cooling duct, a blower was used for air circulation. The air speed was maintained at 4.16 m/sec, when the refrigeration system of system was started and bunker was closed. The air was circulated again and again across the cooling coils of the refrigeration system.

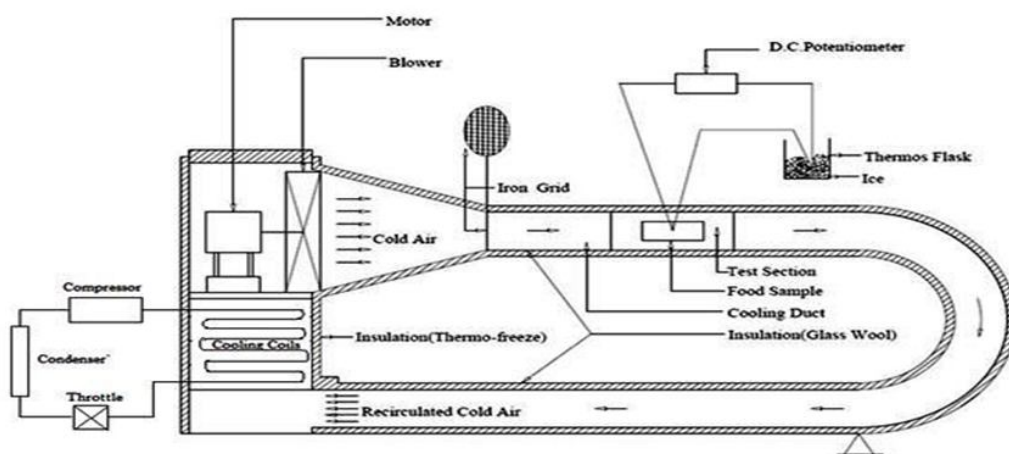


Fig. 1: Schematic diagram of air blast cooling duct

The temperature inside the cooling duct could be maintained at around 10°C and the relative humidity was found to be 100%. Product temperatures were measured using Copper-Constantan Thermocouples. These thermocouples were

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inserted in the food product radially. Temperature-Time variations were measured at five locations from centre to skin. The data for temperature variation was recorded at an interval of one minute.

## CALIBRATION OF THERMOCOUPLE

The copper-constantan thermocouples used for temperature measurement were calibrated after connecting them to the digital DC microvolt ammeter. A mercury thermometer of range 0-100°C and a least count of 1°C were used as a standard. The thermocouple cold junction was fixed in contact with the mercury bulb of the thermometer. This system was then immersed in a flask of crushed ice. Both the thermocouple and thermometer indicated the same temperature (within ± 1°C). The thermocouple calibration formula is already available and is given by:

$$C = 0.011372033 + 25.945621 \times MV - 0.70318373 \times MV^2$$

where, C is temperature in degree centigrade and MV is the digital DC microvolt meter reading.

## METHODOLOGY

Experiments were carried out on spherical shaped food samples. The main aim of these investigations is to analyse the heat transfer behaviour during pre-cooling of solid food products. For this purpose experimental measurement of transient time-temperature behaviour during pre-cooling of food products is done. Potato and brinjal with approximate spherical geometries were all submitted to air cooling in a forced convection environment and the time temperature variation were recorded. Hooks were provided in the air blast cooling duct at the top and bottom walls. The foodsamples were fastened by thin cotton threads and were suspended with the hooks. The air stream velocity in the cooling duct was measured by an anemometer. For measuring the time interval, a stop watch was used. It was a Swies-Racer model with least count of 0.1 sec. The copper-constantan thermocouple was used for temperature measurement which is connected with micro-voltmeter.

## III. OBSERVATIONS

Temperatures along the radial direction were observed at five different locations (from centre to skin) within the product. The observed temperatures were plotted against X (dimensionless radius or distance ratio) at different time intervals of 600 seconds as shown in Fig. 2 and Fig. 3 Temperature-distance ratio plot at different time interval for potato and brinjal on U-duct respectively. Further, these temperatures points were joined to give distribution of temperature along the radial direction inside the products.

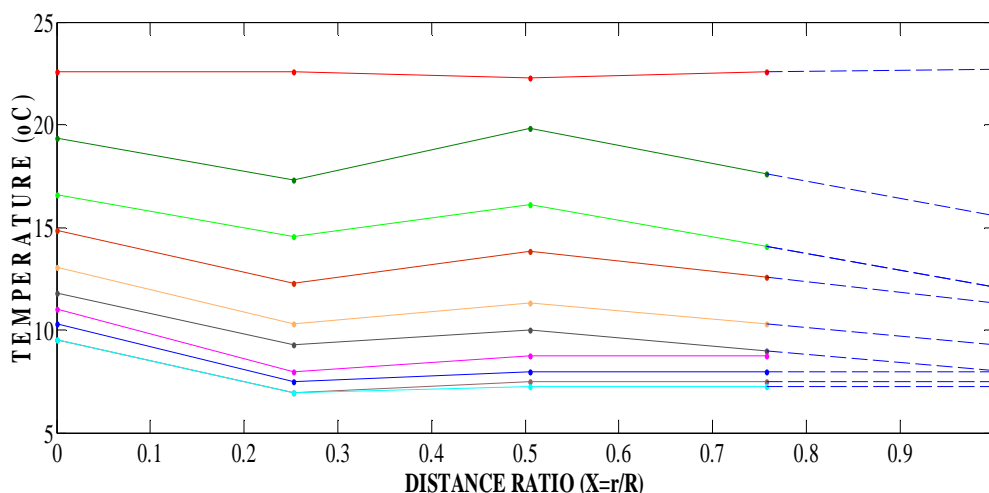


Fig.2: Temperature-distance ratio plot at different time interval for potato on U-duct

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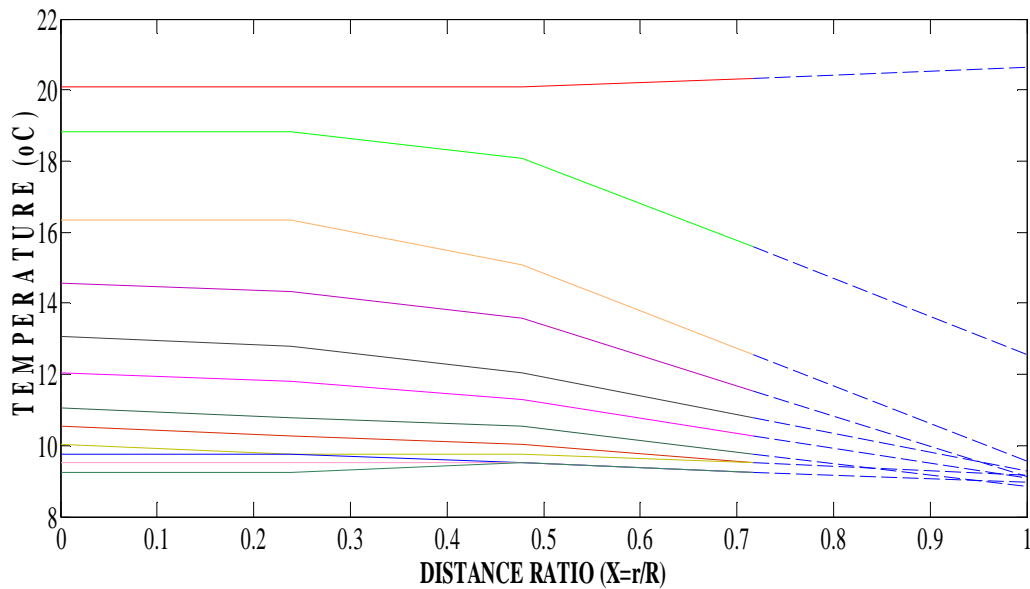


Fig.3: Temperature-distance ratio plot at different time interval for brinjal on U-duct

These curves were then extrapolated to skin ( $x = 1$ ) using Matlab 7.5 as shown by dotted lines in the above figure to determine the skin temperature. The values of skin temperatures were plotted against time as shown in the Fig.4 and Fig.5 Variation of skin temperature with time for potato and brinjal on U-duct respectively.

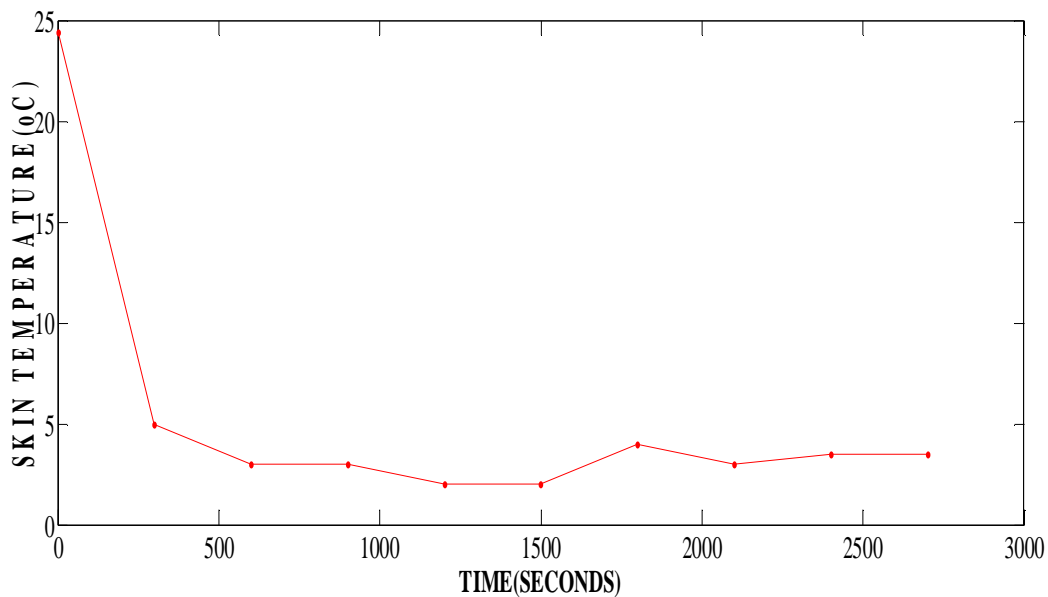


Fig. 4: Variation of skin temperature with time for potato on U-duct

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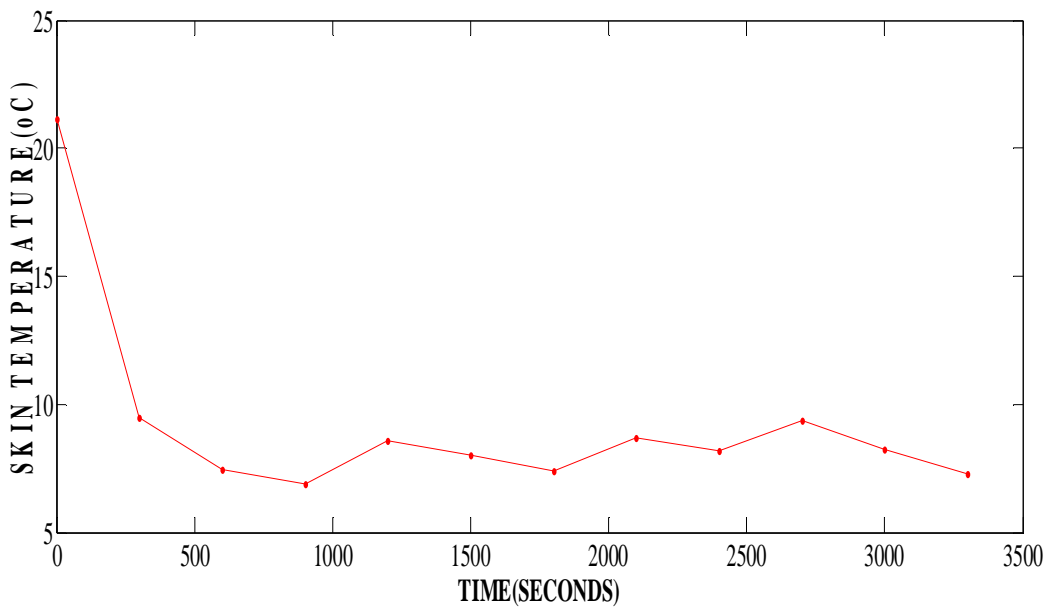


Fig. 5: Variation of skin temperature with time for brinjal on U-duct

## IV. RESULTS AND DISCUSSIONS

The cooling of solid products of characteristic dimension (half thickness)  $L$ , placed in air medium of constant temperature  $T$ , with a constant heat transfer coefficient. The heat transfer is assumed to be one dimensional and unsteady state. Also it is assumed that, there is no effect of latent heat on the heat transfer rate due to quite low moisture content of the cooling medium. For such a situation, the governing time dependent heat conduction equation without internal heat generation and moisture loss can be written as-

$$\frac{\partial^2 T}{\partial X^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

Where,

- T = variation of temperature
- X = radius ratio
- $\alpha$  = thermal diffusivity ( $m^2/s$ )
- t = time(s)

Consider equation (1), the left hand side of its represent the double derivative of non-dimensionalized temperature difference w.r.t distance ratio. This is calculated at the skin (i.e.  $X=1$ ) and for each value of time by using temperature variation across radius of the product. While the right hand side of this equation, which represents single derivative of non-dimensionalized temperature difference w.r.t time. This again calculated at skin for each value of time using the variation of skin temperature. The equation of regression curves passing through the data points is obtained using “Basic Curve Fitting” option provided in the software Matlab 7.5. Solving equation (1) at a time interval of 600 seconds, we get the value of thermal diffusivities corresponding to skin temperature at a particular time intervals for both food samples. The plots of thermal diffusivities Vs Skin temperature is shown in the Fig. 6 and Fig. 7.

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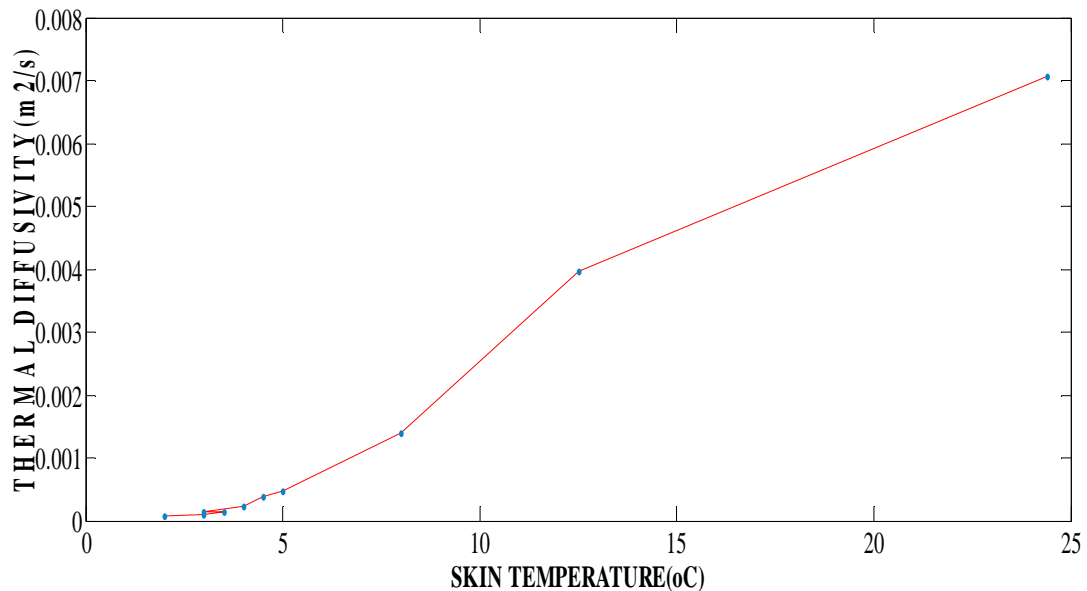


Fig.6:Thermal diffusivity Vs skin temperature forpotato

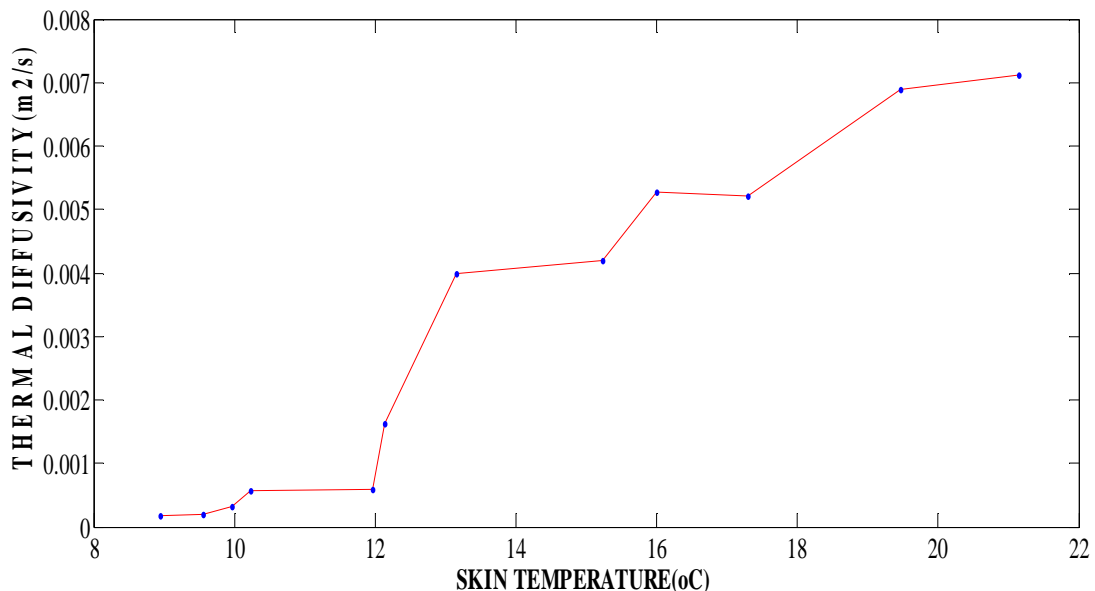


Fig. 7: Thermal diffusivity Vs skin temperature for brinjal

Thus, the curve of Thermal Diffusivity Vs Skin Temperature for both the samples shows that at higher temperature thermal diffusivity shows strong dependence on temperature. i.e as temperature increases thermal diffusivity also increases. The thermal diffusivity continuously increases with temperature for Potato and for Brinjal it remains constant below 12 °C and increases with temperature above 12 °C.

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## EMPERICAL CORRELATIONS

The following empirical correlations are developed by polynomial regression method for thermal diffusivity-temperature curves for two samples

$$\alpha = AT^3 + BT + CT + D$$

The regression coefficient A, B, C and D for each samples are given in the Table-1, Table showing regression coefficient A, B, C and D for brinjal and potato respectively.

COEFFICIENTS SAMPLES	A	B	C	D
BRINJAL	5.1E-06	-1.9E-04	2.4E-03	-8.8E-03
POTATO	3.8E-05	-1.2E-03	7.1E-03	1.0E-02

Table 1: Table showing regression coefficient A, B, C and D for Brinjal and Potato respectively

## V. CONCLUSIONS

A simple experimental approach to find skin temperature for forced convection cooling has been developed as the same cannot be measured by ordinary means. The method comprises of extrapolating the distance ratio curves up to the skin (i.e. distance ratio=1). Thermal diffusivities of the food products at the skin have been calculated and empirical correlations for Potato and Brinjal in forced convection cooling environment have been developed for the variation of thermal diffusivity at the skin with temperature. It shows that the thermal diffusivity continuously increases with temperature for Potato and for Brinjal it remains constant below 12 °C and increases with temperature above 12 °C.

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