Original article

Precooling parameters of `Roxo de Valinhos´ figs (*Ficus carica* L.) packed in a carton box

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Precooling parameters of 'Roxo de Valinhos' figs (*Ficus carica* L.) packed in a carton box.

Abstract — **Introduction**. Figs of the variety 'Roxo de Valinhos' are currently cooled in a cold room at a temperature between (1 and 3) °C, and it is unknown how long it takes to cool the fruits to that temperature. The work was based on the need to determine the parameters of forced-air precooling of figs packed in a carton box used for exportation and commercialization in São Paulo State, Brazil. **Materials and methods**. The fruits were harvested at the harvest rami stage (3/4 of maturity) and at size "type 8", corresponding to eight fruits per box, making up a total of 24 fruits per package. Forty-eight packages were utilized, 24 on each side to form a Californian tunnel. The airflow was 2.8 L·s^{-1} per kg of product, with an average velocity of the air of 2.0 m·s^{-1}. The initial interior temperature of the fruits was 20 °C and the final temperature was 1 °C. The evolution of the fig interior temperature was registered. **Results**. The cooling curve was drawn and the exponential analytical model to predict the precooling parameters was made based on the experimental data. The cooling curve of fig showed a typical behavior; the average fruit temperature during precooling presented a rapid fall at the beginning of the cooling, and slowly declined when it was close to the final temperature. **Conclusion**. The cooling time was 110 min, the cooling coefficient was 0.0344 min^{-1}, the Biot number was 1.3 and the convective heat transference coefficient was 23.8 °C·W^{-1}·m^{-2}.

Brazil / *Ficus carica* / fruits / packaging / cold storage / air flow / refrigeration

Paramètres de préréfrigération de figues (*Ficus carica* L.) 'Roxo de Valinhos' emballées en boîte de carton.

Résumé — **Introduction**. Les figues de la variété 'Roxo de Valinhos' sont actuellement refroidies en chambre froide à une température comprise entre (1 et 3) °C, et le temps nécessaire à leur refroidissement jusqu'à cette température est inconnu. Nos travaux ont été basés sur la nécessité de déterminer les paramètres de la préréfrigération par air forcé de la figue emballée en boîte de carton, telle qu'utilisée pour l'exportation et la commercialisation dans l'état de São Paulo, Brésil. **Matériel et méthodes**. Les fruits ont été récoltés au stade « rami » (3/4 de maturité) et au calibre « type 8 » correspondant à huit fruits par boîte. Nous avons procédé au groupement de 24 fruits par emballage. Quarante huit emballages ont été utilisés, 24 d'entre eux ont été répartis de chaque côté d'une allée pour former un tunnel californien. La circulation d'air a été de 2.8 L·s^{-1} par kg de produit, avec une vitesse d'air moyenne de 2.0 m·s^{-1}. La température intérieure initiale des fruits a été de 20 °C et la température finale a été de 1 °C. L'évolution de la température intérieure des figues a été enregistrée. **Résultats**. Les données expérimentales ont permis de tracer la courbe de refroidissement et de définir les paramètres de préréfrigération à partir d'un modèle analytique exponentiel. La courbe de refroidissement des figues a révélé un comportement typique ; la température moyenne des fruits pendant la préréfrigération a chuté rapidement au début du refroidissement, puis elle a lentement diminué à l'approche de la température finale. **Conclusion**. Le temps de refroidissement a été de 110 min et le coefficient de refroidissement de 0.0344 min^{-1} ; le nombre de Biot a été de 1.3 et le coefficient de transfert de chaleur de convection de 23.8 °C·W^{-1}·m^{-2}.

Brésil / *Ficus carica* / fruits / conditionnement / stockage au froid / flux d'air / réfrigération

1. Introduction

The magnitude of the postharvest losses of fresh fruits is estimated at between (5 and 25)% in the developed countries and up to 50% in developing countries. These values depend on the crop. In the retail and fresh fruit fair trade of São Paulo city (Brazil), losses of figs of up to 20% were observed. The main factors causing these losses were unsuitable packing, transport and storage.

The reduction of the deterioration velocity of fruits, in general, depends on fast heat removal from fruit in postharvest and cold storage at a suitable temperature and relative humidity, besides the handling of the crop during these stages [1–3]. The faster this procedure is realized, the longer the crop can be conserved in good condition for commercialization. If the "cold chain" is broken, the period of conservation, therefore, is reduced due to the reduction of the crop quality. The fig fruit 'Roxo de Valinhos' is a crop with few studies carried out in relation to its shelf life, despite its high perishability.

The precooling method for fruit in a forced-air system, called a Californian tunnel, consists of packing stacks of fruits forming a closed structure and an air suction fan, forcing cold air to pass through the packed fruits. This air is then directed to the evaporator and returns to the cold room. The cooling time is a function of the packing dimensions, opening area and distribution of opening area, besides the fruit characteristics (temperature, water content, specific heat, size, geometry and air velocity through the fruit). The packing must have an opening area of at least 5% in order to maintain cooling uniformity [4].

For fresh fruit precooling in a forced-air system, it is considered necessary for the airflow to be between (0.001 and 0.006) $m^3 \cdot s^{-1}$ per kg of product, which corresponds to (1 to 6) $L \cdot s^{-1}$ per kg of product to be cooled [5, 6].

Our objective was to determine the cooling time and the most important parameters of precooling of fig fruit packed in a carton box used for exportation: the Biot number, the convective heat transfer coefficient and the cooling coefficient.

Figure 1.
The carton box manufactured by the Rigesa® Company utilized for exportation and commercialization of figs in São Paulo State, Brazil.

2. Materials and methods

The experiment was developed in the thermodynamics laboratory of the School of Agricultural Engineering (UNICAMP, Campinas-SP, Brazil). The fig fruits 'Roxo de Valinhos' were harvested at the rami stage (3/4 of maturity) and size type 8, corresponding to eight fruits per box, making up a total of 24 fruits per package. The fruits were harvested in the Region of Valinhos-SP, Brazil (season 2002).

The carton box manufactured by the Rigesa® Company is a box without a cover with the external dimensions: length 35.5 cm, width 26.0 cm and height 7.5 cm, and with a lateral opening area of 28 cm^2 (rectangular space form) (*figure 1*).

To precool the figs, the air flow was 2.8 $L \cdot s^{-1}$ per kg of product, with an average air velocity of 2.0 $m \cdot s^{-1}$. The airflow reversed during precooling to avoid freezing**.** The temperature of the air used for precooling was –1 °C. The initial temperature of the fruits was 20 °C and the final temperature was 1 °C, which is a suitable temperature for fig storage. To calculate the effective air flow into the packing, the effective opening area and the air velocity over the fruits were taken into consideration. Eight points of the internal temperature of the fruits on each side of the Californian tunnel were monitored. The thermocouples (type T AWG # 24) were located on a crossed diagonal line on each side of the Californian tunnel. Forty-eight packages (total 96 kg of product) were utilized, 24 packages on each side, to form the Californian tunnel (two boxes in the width of tunnel and two boxes in the length, resulting in four boxes on the base, and seven boxes in height). There were 24 fruits per package (2 kg per package). The evolution of the internal fruit temperature was registered by a Linx acquisition data system (Aqdados).

Through the experimental data, the cooling curve of the fruit and the adjustment to the exponential model were obtained [2, 7]. For the calculation of precooling parameters, the thermal conductivity, thermal diffusivity and specific heat values of the fig fruit were considered [8].

Each stack of packages at each side of the tunnel was considered as a repetition. The descriptive statistics were applied and the average values of parameters of precooling of the fig fruit were determined.

The calculation procedure and the equations utilized were the following:

– The precooling of horticultural crops presents an exponential behavior [2, 9–11]. The curve of cooling can be described by the equation: $\theta = J \cdot e^{-at}$ (1), where the term corresponds to the adimensional relation of temperatures, t corresponds to the cooling time, J is called "lag factor" and a represents the cooling coefficient.

– The adimensional relation of temperatures, also called adimensional tax of temperatures, is expressed by the equation: $\theta = (T - T_a) / (T_i - T_a)$ (2), where T_i corresponds to the initial temperature of the fruit, T_a is the air cooling temperature and T is the fruit temperature after cooling for some instants.

Once the values of the cooling coefficient (a) in equation (1), expressed in s^{-1}, and the value of the thermal conductivity (k), thermal diffusivity (α) and fruit radius (r) [8] were known, the convective heat transfer coefficient (h_c) was calculated through the equation: $h_c = (3.2\ k \cdot r_a) / (10.3\ \alpha - ar^2)$ (3) [2].

With the h_c value, the Biot number (B_i). was calculated, using the equation $B_i = (h_c \cdot r) / k$ (4), where r is fruit radius and k is the thermal conductivity of the fruit.

3. Results and discussion

At the beginning of the cooling experiment, an increase in the air cooling temperature was observed. This increase was due to the great heat loss of the fruits, causing an increase in the air temperature. In the mathematical calculations, the temperature of the air-cooling was considered to be 0 °C. The average relative humidity was 74%.

The amount of the airflow that crossed the packages next to the fan was greater than the airflow crossing the packages far from the fan. The air velocity was heterogeneous, and the average velocity was considered in all the packing stack.

By the exponential adjustment of experimental data, the following expression was obtained: $\theta = 1.1293\ e^{-0.0344\ t}$ (5).

Therefore, the cooling coefficient (a) was 0.0344 min^{-1}. The cooling curve was plotted and obtained, and the exponential adjustment equation and the determination coefficient (R^2) were calculated (*figure 2).*

In the exponential adjustment of experimental values, a high determination coefficient of the cooling curve (98%) was observed, which means that the exponential model is suitable and represents the precooling behavior of 'Roxo de Valinhos' fig fruit, and the cooling coefficient can be considered reliable. The experimental cooling time of the fig fruit to go from 20 °C to 1 °C was 110 min.

The cooling curve of the fig fruit shows the typical behavior mentioned by several

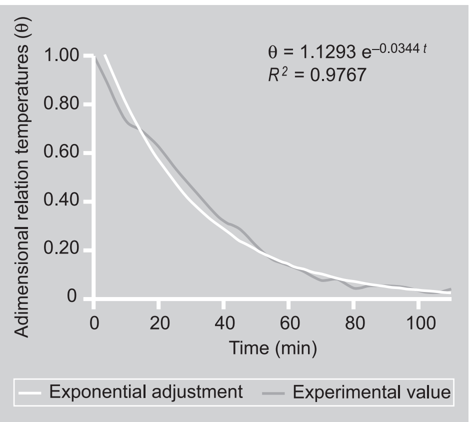

Figure 2.
Distribution of experimental temperatures and curve adjustment for precooling figs packed in a carton box (v = 2.0 $m \cdot s^{-1}$).

authors [1, 2, 7, 12]. The average fruit temperature during precooling presents a rapid fall at the beginning of the cooling and declines slowly when it is near the final temperature.

When forced air is used in precooling of fruits, the percentage of opening area in the package is very important [5, 7, 11]. The suitable opening area is between (5 and 10)% for air flow, and correctly distributed to guarantee cooling uniformity [4]. The Rigesa® package exhibited a suitable opening area percentage of 10.5%, but it could be better located for more efficient air flow. In these conditions, the convective heat to transfer coefficient value was approximately 24 $°C \cdot W^{-1} \cdot m^{-2}$, similar to the value published for the fig variety 'Brown Turkey' [2, 3, 13, 14].

Experimentally, the heat transfer rate of fig fruit is a function of real cooling conditions. Factors such as packaging, which is a barrier to the air flow crossing, the air velocity, temperature and relative humidity, cooling air oscillations and the heat generated from other sources do not permit appropriate heat transference.

Several works have presented the precooling parameter values of individual Turkish figs (Brown Turkey) [2, 3, 13, 14]. The convective heat transfer coefficient values of Turkish figs were superior to those of the fig fruit 'Roxo de Valinhos' [between (24 and 33) $°C \cdot W^{-1} \cdot m^{-2}$] for air velocity between (1.1 and 2.5) $m \cdot s^{-1}$; on the other hand, the hc value of the fig fruit 'Roxo de Valinhos' was 23.8 $°C \cdot W^{-1} \cdot m^{-2}$.

In comparison to the fig fruit 'Roxo de Valinhos', the Turkish fig presents a different size (diameter: 0.047 m), mass (0.058 kg) and water content (78%). In the experiment realized by Dincer [3], the fruit was hung in order to allow the air flow to pass entirely around it, and, in the case of this work, the precooling was realized in real conditions of handling. The fig fruit 'Roxo de Valinhos' presents different physical properties. Fruits of different size and form answer differently to precooling in a forced-air system at similar air flows [15]. In cooling systems with convective condition [12], the cooling time is proportional to the Biot number (equation 4)

The Biot number is the ratio between convection heat transfer (between the fruit and cooling air) and conduction heat transfer (into the fruit). In our work, the Biot number was 1.3, which is a low value. This value expresses small internal fruit resistance to heat transfer and great external resistance; it is the usual behavior in heat transfer of fruits and vegetables.

4. Conclusions

The forced-air precooling of the fig fruit 'Roxo de Valinhos' packed in a carton box showed typical exponential behavior. The air velocity profile in the packing stack was heterogeneous. The carton box manufactured by the Rigesa® Company is appropriate for precooling with forced air of fig fruit. The cooling time was 110 min. The cooling coefficient was 0.0344 min^{-1}. The convective heat transfer coefficient value was 23.8 $°C \cdot W^{-1} \cdot m^{-2}$ and the Biot number was 1.3.

Acknowledgements

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References

[1] Turk R., Effects of harvest time and pre-cooling on fruit quality and cold storage of *Ficus carica* L. cv. 'Bursa syahjiu', Acta Hortic. 258 (1989) 279–285.

[2] Dincer I., Thermal cooling data for figs exposed to air cooling, Int. Commun. Heat Mass Transf. 22 (1995) 559–566.

[3] Dincer I., Transient heat transfer analysis in air cooling of individual spherical products, J. Food Eng. 26 (1995) 453–467.

[4] Leal P.A.M., Cortez L.A.B., Métodos de pré-resfriamento de frutas e hortalizas, in: II Curso Atual. Tecnol. Resfr. Frut. Hortal., Fac. Eng. Agríc. (UNICAMP), Campinas-SP, Brazil, 1998, pp. 81–91.

[5] Talbot M.T., Chau K.V., Precooling strawberries, Inst. Food Agric. Sci., Univ. Fla., Circ. 942, USA, 1991.

[6] Fraser H.W., Forced-air cooling of fresh Ontario fruits and vegetables, Minist. Agric. Food., Toronto, Ontario, 1991.

[7] Chau K.V., Mathematical modelling of postharvest processes, Grupo Tecnol. Pós-Colheita, Univ. Estadual Campinas, Fac. Eng. Agríc., Campinas-SP, Brazil, 2001.

[8] Dussán-Sarria S., Honório S.L., Condutividade e difusividade térmica do figo (*Ficus carica* L.) 'Roxo de Valinhos', Rev. Bras. de Eng. Agríc. 24 (2004) 185–194.

[9] Mohsenin N.N., Thermal properties of foods and agricultural materials, Gordon Breach Sci. Publ., New York, USA, 1980, pp. 198–224.

[10] Goyette B., Vigneault C., Panneton B., Raghavan G.S.V., Method to evaluate temperature at the surface of horticultural crops, Can. Agric. Eng. 38 (1997) 292–295.

[11] Anon., Methods of precooling fruits, vegetables and ornamentals, Am. Soc. Heat. Refrig. Air-Cond. Eng. (ASHRAE), Refrigeration handbook Inc., Atlanta, Georgia, USA, 1998, pp. 14.1–14.10.

[12] Teruel M.B., Estudo teórico – experimental do resfriamento de laranja e banana com ar forçado, Univ. Estadual Campinas, Fac. Eng. Mec.,Thesis, Campinas, Brazil, 2000, 300 p.

[13] Dincer I., Cooling parameters and film conductances of spherical products cooled in an air flow, Appl. Energy. 50 (1995) 269–280.

[14] Dincer I., Simplified solution for temperature distributions of spherical and cylindrical products during rapid air cooling, Energy Convers. Manag. 36 (1995) 1175–1184.

[15] Baird C.D., Gaffney J.J., Talbot M.T., Design criteria for efficient and cost effective forced-air cooling systems for fruits and vegetables, ASHRAE Trans. 94 (1988) 1434–1453.

Parámetros de prerrefrigeración de higos (*Ficus carica* L.) 'Roxo de Valinhos' embalados en caja de cartón.

Resumen — **Introducción**. Los higos de la variedad 'Roxo de Valinhos' se refrigeran actualmente en cámara frigorífica bajo una temperatura comprendida entre (1 y 3) °C, y se desconoce el tiempo necesario para su enfriamiento hasta dicha temperatura. Nuestros trabajos se basaron en la necesidad de determinar los parámetros de la prerrefrigeración mediante aire forzado del higo embalado en caja de cartón, prerrefrigeración utilizada para la exportación y comercialización en el estado de São Paulo, Brasil. **Material y métodos**. Los frutos se cosecharon en el estado "rami" (3/4 de madurez) y de calibre "tipo 8" que corresponde a ocho frutas por caja. Procedimos a la agrupación de 24 frutos por embalaje. Se usaron 48 embalajes, de los cuales 24 se repartieron en ambos lados de una recta con el fin de formar un túnel californiano. La circulación del aire fue de 2.8 $L \cdot s^{-1}$ por kg de producto, con una velocidad media de aire de 2.0 $m \cdot s^{-1}$. La temperatura interior inicial de los frutos fue de 20 °C y la temperatura final fue de 1 °C. Se registró la evolución de la temperatura interior de los higos. **Resultados**. Los datos experimentales permitieron trazar la curva de enfriamiento así como definir los parámetros de prerrefrigeración a partir de un modelo analítico exponencial. La curva de enfriamiento de los higos mostró un comportamiento típico; la temperatura media de los frutos durante la prerrefrigeración cayó acentuadamente al principio del enfriamiento, y disminuyó lentamente según se acercaba a la temperatura final. **Conclusión**. El tiempo de enfriamiento fue de 110 min y el coeficiente de enfriamiento de 0.0344 min^{-1}, la cantidad de Biot fue de 1.3 y el coeficiente de traspaso de calor de convección de 23.8 $°C \cdot W^{-1} \cdot m^{-2}$.

Brasil / *Ficus carica* / frutas / empaquetado / almacenamiento en frío / flujo de aire / refrigeración