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Innovative Parallel Airflow System for forced-air cooling of strawberries

Habibeh Nalbandi[a,*], *Sadegh Seiiedlou*[a], *Hamid R. Ghasemzadeh*[a], *Faramarz Rangbar*[b]

[a] *Department of Biosystem Engineering, Faculty of Agriculture, University of Tabriz, Tabriz, Iran*
[b] *Department of Mechanical Engineering, Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran*

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ABSTRACT

Strawberry is a high value crop and mostly is consumed as a fresh fruit over the world. Precooling of strawberry is one of the postharvest processes that reduces the fruit decay. However, in the traditional cooling system of strawberry considerable differences are observed between the fruit temperature located in the individual packages as well as in the various packages inside the tray. As a result, the self-life of fruit decreases. The aim of this research was introducing the new package and cooling system for precooling of strawberry in which some improvements were made in the uniformity of cooling of strawberry and reduced the fruit decay. The cooling process of strawberry was simulated based on simultaneous airflow and heat transfer process inside the new system and the developed model was validated experimentally, and a good agreement observed between the simulated and measured temperature of fruit. The results of simulator and experimental data showed that the new system had the higher uniformity in the cooling of fruit as compare with the traditional system so that the packages located along the cold air direction received the equal airflow rate. As a result, a difference of 0.84 °C was measured in the average fruit temperature of the packages after 3 h of cooling meaning that the differences in the 7/8th cooling time of fruit between the packages is negligible. Therefore, with the same airflow rate of traditional system, the cooling time of strawberries could be reducing by the proposed system significantly.

1. Introduction

Strawberry is a high value crop and mostly is consumed as fresh fruit, i.e., over 75% of the product is delivered by fresh produce market. However, it is one of the most perishable fruit and is susceptible to mechanical damage, microbial decay and water loss. These prevent the product, in some cases, reaching the consumer at its optimal quality after transport and distribution (Anderson et al., 2004; Manganaris et al., 2007).

Good temperature management is a key factor for delaying product deterioration, maintaining product quality and extending its shelf life. The cooling of fruit and vegetables from ambient temperature down to a proper temperature controls the microbial activity, retards the ripening process, and reduces respiration, wilting and shriveling due to moisture loss. Two hours delay in cooling of strawberry is long enough to reduce the proportion of marketable fruit dramatically (Kader, 2002).

Among various precooling techniques, forced-air cooling is widely accepted as an appropriate method for cooling of most fruit such as strawberry (Becker et al., 1996; Brosnan and Sun, 2001; Chakraverty and Paul, 2001; Anderson et al., 2004; Castro et al., 2005; Tutar et al., 2009). Poor airflow distribution at different locations in the package leads to considerable heterogeneities in the final temperature of product (Alvarez and Flick, 1999a; Amara et al., 2004; Dehghannya et al., 2011).

Many researchers have used some experimental methods to study the factors that affect the airflow pattern and cooling efficiency (Alvarez

* *Corresponding author*.
E-mail addresses: habibehnalbandi@yahoo.com, h.nalbandi@tabrizu.ac.ir (H. Nalbandi).
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Nomenclature

CFD	Computational Fluid Dynamics
C_p	Specific heat capacity (J/(kg °C))
k	Thermal conductivity (W/(m °C))
MPAS	Modified Parallel Airflow System
n	Outward vector normal to the surface
PAS	Parallel Airflow System
P	Pressure (Pa)
t	Time (s)
T	Temperature (°C)
u	Velocity (m/s)
μ	Dynamic viscosity (Pa s)
ρ	Density (kg/m^3)

Subscripts

p	Product
a	Air

and Flick, 1999a,b; Amara et al., 2004; Anderson et al., 2004; Castro et al., 2004; Vigneault et al., 2006; Kumar et al., 2008). However, there are some problems associated with experimental studies such as being expensive, time consuming and situation specific (Zou et al., 2006a).

To overcome these problems, mathematical approaches have been developed to model the transport phenomena inside the packages, for predicting the temperature and airflow patterns and cooling homogeneity. The medium inside the packages were considered as a porous medium in most of these models (Zou et al., 2006a,b; Van der Sman, 2002). This assumption was made due to limitations in computational resources. Even though the computational method is cost-effective, inevitable simplifications made in porous medium approach, lead to considerable errors in predictions (Dehghannya et al., 2008; Ferrua and Singh, 2009b).

Recent advances in the computational resources and decreasing cost of modern computers have made the application of CFD modeling more efficient and popular and provided more powerful tool for solving the fundamental continuity, momentum and heat transfer equations and predicting the airflow patterns and temperature variation in the packages. The mathematical modeling capability of predicting the cooling process of fruit within the packages has been used as an ideal approach by many researchers, especially when the container-to-product equivalent diameter ratio was under 10, e.g., strawberry packages. In such situation, the porous medium approach could not be used (Dehghannya et al., 2010; Ferrua and Singh, 2011).

Some researchers studied the cooling process of strawberry using various package and tray designs as well as pallet arrangements (Anderson et al., 2004; Ferrua, 2007; Ferrua and Singh, 2009a,b,c,d, 2011). In the forced-air cooling system that is shown in Fig. 1a, the cold air is forced across each palletized row (Fig. 1b and c), through the vents in the trays and packages (I in Fig. 1d) due to the negative relative pressure created by the system suction fan. Therefore, the cold air enters from the right side of each row and the warmer air exits from the left side (Fig. 1d). There are some problems associated with this method. Firstly, the air temperature entering to the various packages is not the same as it travels along the packages. The warmer exiting air from package 1 (P1) enters the next one (Fig. 1d), as a result the air temperature increases gradually as an in-series method. As a result, there was about 6 °C difference in average fruit temperature between P1 and P8 after 1 h of cooling process (airflow rate: 1 L/(s kg_p)). In the in-series method, modifying the package and/or tray would not improve the rate and uniformity of the cooling process; because the air temperature still rises as it travels along the systems (Ferrua and Singh, 2009d). Therefore, the last package (P8) always receives higher temperature air than the first one (P1). The higher air temperature leads to a lower heat removal rate. Secondly, the most of total cold airflow bypasses the system with-

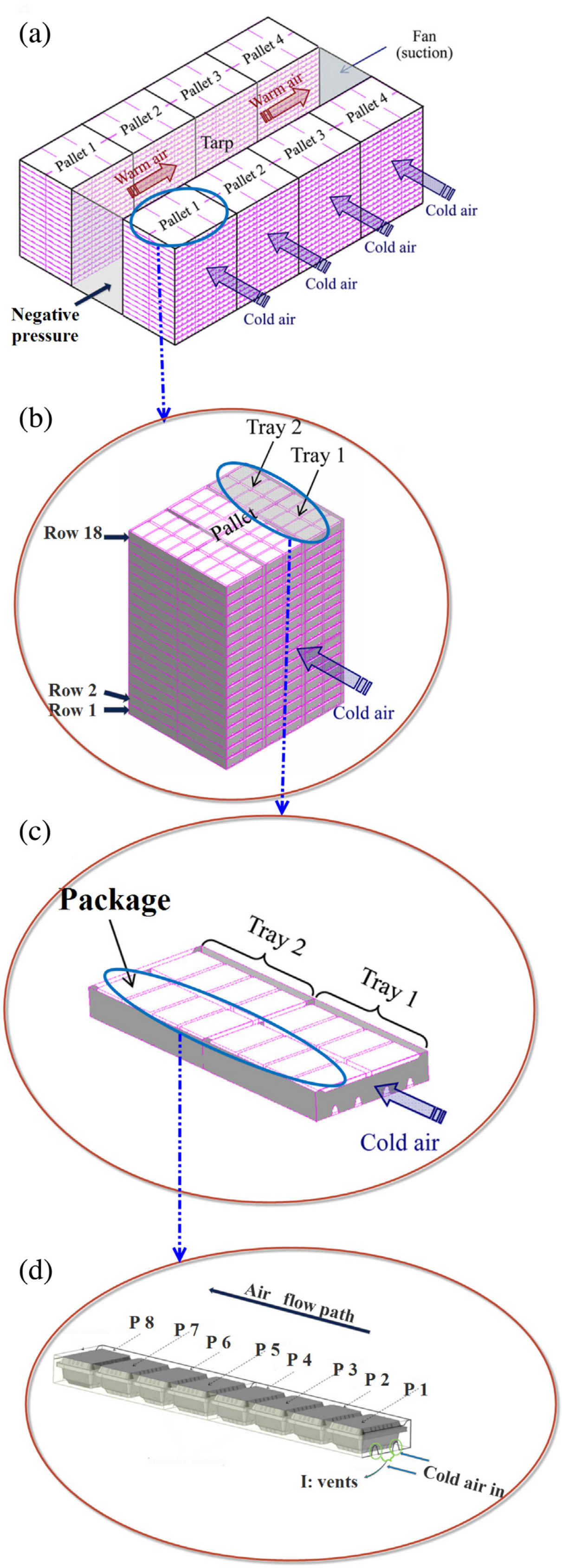

Fig. 1 – The industrial forced-air cooling system of strawberries (Ferrua and Singh, 2009d).