LOW-COST GREENHOUSE TECHNOLOGY FOR DRYING ONION (*ALLIUM CEPA* L.) SLICES

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ABSTRACT

The performance of the greenhouse solar heat collector was highly dependent on the solar radiation, ambient temperature and relative humidity. Increase in air temperature inside greenhouse varied from 0.7 to 19.0C, and relative humidity inside greenhouse varied from −16 to 25.7% by air exchange at a flow rate of 6.1 m^3/s. *The average midday thermal efficiency was around 20.82%. The cured red onion (*Allium cepa *L.) bulbs were cleaned, outer layer was peeled and trimmed manually, and washed in water to remove dirt and infection. Edible bulb of onion was sliced into 3-mm thick slices by using manual stainless steel slicer. The onion slices were pretreated with sodium chloride, and potassium metabisulphite, for 5 min in three concentration levels (0.25, 0.50 and 0.75%) and drained onion slices were spread in thin layers in trays before keeping them in greenhouse for drying. Onion slices were dried in 19 sunshine hours. Preservatives used as pretreatment in 3-mm sliced onion were found to be significantly different (probability,* $P < 0.05$*) from each other. It was found that 0.50% potassium metabisulphite was best.*

PRACTICAL APPLICATIONS

Availability of solar energy is abundant in the Indian subcontinent and drying of agricultural produce using low cost greenhouse is one of the latest developments when crop production is not possible in greenhouse during

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summer season. Low cost greenhouse can be utilized to dry the onion slice as alternative to conventional mechanical dryers. Greenhouse drying can be used for the preparation of shelf-stable dehydrated onion slices for the purpose of use during off-season. The quality of dehydrated onions is good and it can be stored for months together. Dried onion slices can be used same as fresh onion after rehydration, apart from this, it can be added directly into soups, etc., before cooking.

INTRODUCTION

Drying involves the removal of moisture contained in fruits and vegetables in order to preserve. Although preservation for enhanced shelf life is the primary reason for drying, it also lowers the product mass and volume. The reduction in mass and volume improves the efficiency of packaging, storing and transportation. Traditionally, fruits and vegetables are dried in open sunlight, which is weather dependent and also prone to microbial and other contamination. To get best quality, dried product hot air industrial dryers are quite prevalent but require huge amount of energy. Steep rise in energy cost on one hand and strict legislation of environmental pollution on the other hand have created greater demand for energy efficient drying processes in the food industry. Avoiding wastage of costlier energy can benefit the food industry and it has been reported that improving energy efficiency by 1% could result to 10% increase in profits (Beedie 1995).

Use of nonconventional source of energy (renewable) for drying of vegetables and application of pretreatments of preservatives for improvement in quality retention of dried product has been a major research goal for better efficiency of drying and quality of dried product (Cohen and Yang 1995). Solar energy, being abundantly available in tropical and subtropical regions of the world, being environmentally benign and which could not be monopolized (Imre 1987) can effectively be utilized for drying of agri-produce, if harvested properly. In this direction, drying of produce inside greenhouse (GH) by harvesting solar energy during hot months (summer) is one of the latest developments. Efforts have been made to convert GH into drying chambers during hot months so that the same facility can be utilized for drying purposes. Kadam and Samuel (2006) developed a flat plate heat collector for drying cauliflower. During the process, rise in drying air temperature ranged from a minimum of 1.7C to a maximum of 13.5C, whereas a reduction of relative humidity (RH) ranged from a minimum of 1.59% to a maximum of 10.5% by passing through flat plate solar heat collector at a mass flow rate of 4.81 m^3/sec.

Onion (*Allium cepa* L.) is one of the major bulb crops of the world and is one of the most important commercial vegetable crops grown in India. A large quantity of onion is used fresh; however, the surplus quantity in the market is processed by dehydration for export (Pawar *et al.* 1988). Dehydration of onion is one of the economic and feasible methods of preservation of surplus produce. Dehydrated onions are becoming a product of considerable importance in international trade. Out of total dehydrated vegetables export from developing countries, dehydrated onion has the largest share of 45% (Kortbech-Olesen 1982). Chadha (1995) reported that dried and processed vegetables constitute 40–42% of total export of processed products, prominent among them were dehydrated onion flakes and powdered onion. Singhal (1996) reported that India is the largest exporter of dehydrated onion products followed by The Netherlands and Spain. Little information is available on the effect of pretreatments on the quality characteristics of dehydrated onion slices. The quality losses in dried onions during storage at different temperatures (20, 30 and 45C) and different water activities were studied and this study showed that nonenzymatic browning follows a zero order reaction, while thiosulphinate loss follows a second order reaction during drying and storage (Kaymak-Ertekin and Gedik 2005). Recently, Raj *et al.* (2006) reported that onion rings pretreated with 0.25% potassium meta-bisulphite (KMS), $K_2S_2O_5$ were better for the dehydration and had significantly less increase in moisture, reducing sugars, while significantly has less decrease in their dehydration sugar, ascorbic acid and acidity during storage. Preservatives help to retain quality parameters of dehydrated onion and reduce discoloration during storage. Considering these points, systematic studies were conducted to study the efficiency of low-cost GH for drying onion slices with pretreatments during summer, and to determine the thermal efficiency of the low-cost GH for drying onion slices on the quality of slices.

MATERIALS AND METHODS

An alternate approach was developed to convert low-cost GH as a solar heat collector to utilize GH for drying purposes during summer (May–July), which otherwise cannot be utilized for production of high value crops due to prevailing high temperature. GH-type solar heat collector is more favorable than other solar collectors in terms of energy per unit cost. A low-cost GH drying technology was developed and the experiment on sliced onion drying was conducted at Central Institute of Post-Harvest Engineering and Technology (CIPHET), Abohar, Punjab, India. Ambient (outside GH) and inside GH observations of air temperature, relative humidity (RH) and solar radiation were recorded with three replications on an hourly basis. The experiment was repeated five times.

Low-Cost GH Structure

The studies were conducted at CIPHET, Abohar (Lat 30° 09′N, 74° 13′E, 185.6 m above mean sea level), Punjab, India. This region falls in semi-arid zone, having hot summers (May–July) and mild winters (December–February). The experiment on drying of onion slices was conducted in a Quonset shape low-cost GH (6 m long by 4 m wide, with central height of 1.8 m, having total volume of 32.75 m^3) with main axis oriented East–West direction. The GH frame was constructed with local material like bamboo, which was covered with 0.2-mm thick UV stabilized film (Indian Petro-Chemical Limited, Mumbai, India). The GH was equipped with a 9-inch diameter exhaust fan placed opposite the door (1.8 m × 1 m), which had the capacity of delivering an airflow rate of 0.16 m^3/s to remove the moisture accumulated in GH during drying. Exhaust fan air velocity was approximately 0.3 m/s, which was measured by means of a vane anemometer (LT Loutron from Gemini data loggers, U.K. Ltd., England) having a resolution of 0.01 m/s. The front and close views of low-cost GH constructed for the experimentation are shown in Figs. 1 and 2.

Inside and Outside GH Air Condition

GH and ambient air temperature (C) and RH (%) were recorded using digital temperature-RH meter (Sika Electronic, Vaiseshika Electron Devices, Ambala, India) for 8–9 h a day at an interval of 1 h from morning (8:00–9:00 a.m.) to evening (5:00 p.m.). Simultaneously, GH inside and outside solar radiation was measured by pyranometer in W/m^2.

FIG. 1. FRONT VIEW OF LOW-COST GREENHOUSE USED FOR DRYING OF ONION SLICES

FIG. 2. CLOSE VIEW OF INSIDE GREENHOUSE
(a) Onion slices drying in the tray and black sheet laid on ground surface for better heat collection.
(b) Dehydrated onion slices packed in polypropylene.

Sample Preparation

The cured red onion (average diameter 4.96 cm with average height 4.56 cm) was procured from local market, Abohar, Punjab, India. Cleaning, peeling, and trimming of procured red onions were done manually and onion bulbs were washed in cold water to remove dirt, infection, etc. Edible bulbs of onion were sliced uniformly (average thickness 3.0 ± 0.5 mm) by using manual stainless steel slicer. The initial moisture content of onion was 86.07% wet basis (w.b.) with total soluble solids (TSS) (12.7 °Brix) and was determined by the AOAC method no. 934.06 (AOAC 2000).

Pretreatments and Drying

The onion slices were weighed and dipped in sodium chloride (NaCl) and KMS for 5 min in three concentration levels (0.25, 0.50 and 0.75%). After pretreatment, onion slices were drained for 5 min to remove surface moisture and spread in trays with a loading rate of 500 g per 0.135 m^2 (i.e., 3.70 kg/m^2). The sample thickness in the drying trays was 3 mm, i.e., a single layer, and trays filled with onion slices were kept in the greenhouse on racks for drying. Experiments were replicated three times to minimize error.

Thin layer drying assumes complete exposure of the product to heated air. The drying action can be represented on the basis of Newton's law

$$\frac{dT}{d\theta} = -K\left(T_{ig} - T_a\right) \quad (1)$$

where T_{ig} is the air temperature inside *GH* in *C*; T_a is the ambient temperature in *C*; θ is time in hours and *K* is the drying constant.

By replacing moisture content in place of temperature

$$\frac{dM}{d\theta} = -K\left(M - M_e\right) \tag{2}$$

where *M* is the moisture content at time θ in % d.b.; and M_e is the equilibrium moisture content in % d.b.

Integrating between limits gives the moisture ratio M_R:

$$M_R = \frac{M - M_e}{M_0 - M_e} = e^{-K\theta} \tag{3}$$

Statistical Analysis

The experiment was conducted using a factorial completely randomized design (CRD) with two preservatives, three preservative concentration levels and three replications each ($2 \times 3 \times 3 = 18$) and it was repeated for four times. Data were analyzed as per procedure factorial CRD using Agres statistical software version 3.01 (1994). If the factorial effects are found to be significantly different through ANOVA, then these were subjected to multiple comparison procedure using least significant difference at 5% level of significance. The identification of best treatment combinations was done through one-way classified ANOVA followed by multiple comparison procedure.

RESULTS AND DISCUSSION

Performance of the GH as Heat Collector

GH performance as solar heat collector was compared with ambient environmental conditions during the period of experimentation. Figure 3 presents the trend of ambient and inside GH air temperature, RH and solar radiation. GH performance was evaluated as solar heat collector (dryer) based on the availability of sunlight to raise the air temperature and reduce RH inside GH. The performance of the GH as solar heat collector was highly dependent on the solar radiation, ambient temperature and RH. It is evident from Fig. 3 that solar radiation has direct effect on increase in ambient and inside GH air temperature and reducing RH in both environment. The temperature and RH difference between ambient and inside GH was low in the morning and evening periods as compared to the afternoon. Based on the calculations,

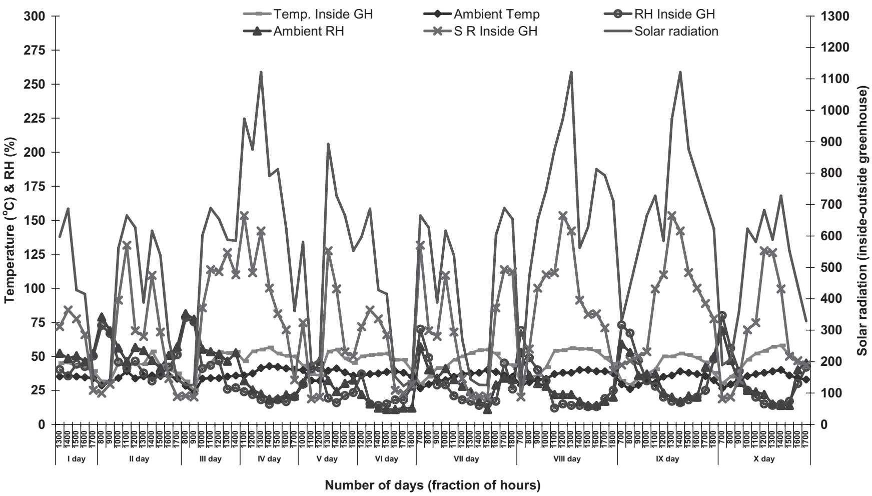

FIG. 3. EFFECT OF SOLAR RADIATON ON AMBIENT CONDITIONS AND AIR TEMPERATURE (C) AND RH (%) INSIDE GREENHOUSE DURING EXPERIMENTATION (2005)

where the experiment was conducted, has potential sunshine duration of 7–8 h/day compared to the monthly mean of 7:73 h/day (Kadam and Samuel 2006). Increase in air temperature inside GH varied from 0.7 to 19.0C, and RH inside GH varied from −16 to 25.7% by air exchange at a flow rate of 6.1 m^3/s.

Thermal Efficiency of the GH

The observed ambient temperature, humidity and solar radiation ranged between 23.1 to 42.8C, 11.0 to 81.4% and 123 to 1,121 W/m^2, respectively, during the period of experimentation. Temperature, RH and solar radiation inside GH varied from 25.0 to 58.0C, 12.0 to 80.0% and 81 to 665 W/m^2, respectively.

According to the solar collector theory (Duffie and Beckman 1991), the instantaneous efficiency η in % is defined as:

$$\eta = C_p m_a (T_{ig} - T_a) / (A_s I) \tag{4}$$

where C_p is the air specific heat in KJ/kg/C; m_a is the air mass flow rate in kg/s; T_{ig} is the air temperature inside GH in *C*; T_a is the ambient air temperature in *C*; A_s is the surface area of GH in m^2; and *I* is the solar radiation in W/m^2.

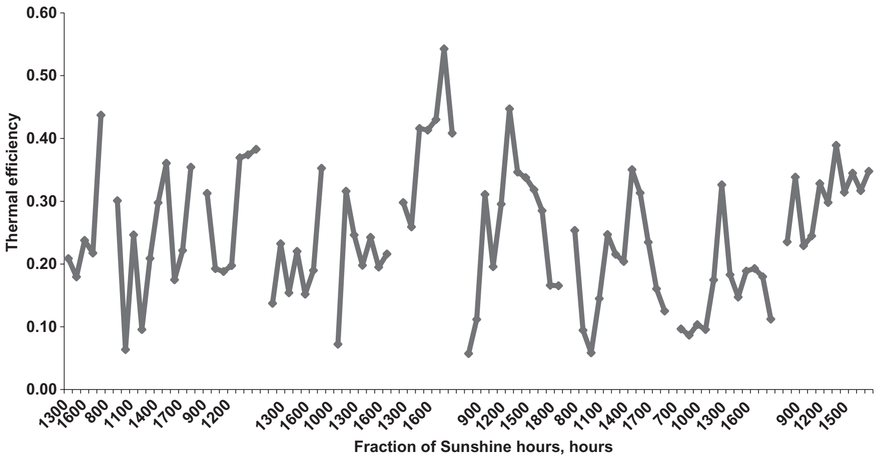

FIG. 4. THERMAL EFFICIENCY OF THE GREENHOUSE FOR ONION DRYING

The daily records for the GH as heat collector instantaneous thermal efficiency corresponding to 10 days are shown in Fig. 4. The average midday efficiency was around 20.82% and the peaks are due to the inertial effect that keeps the temperature inside GH almost constant for some minutes when the radiation falls. The parameter values adopted in the above Eq. (4) are: C_p is 1 KJ/kg/C; m_a is 6.1 kg/s; $\tau\alpha$ is 0.8; and A_s is 24 m^2.

Since the air inside the GH is ambient one, the thermal efficiency only depends on the inside GH heat removal factor F_R and the GH ultraviolet polyethylene sheet optical parameters:

$$\eta = F_R(\tau\alpha) \tag{5}$$

where τ is the transmittance of the cover; and α is the collector mean absorption coefficient.

The solar heat collecting efficiency of GH was practically constant for daily values since τ and α did not change and F_R mainly depended on the mass flow, which was constant, i.e., 6.1 kg/s (Eq. 5). Kadam and Samuel (2006) reported similar results for solar drying of sized cauliflower using the flat plate heat collector and Condori *et al*. (2001) for solar drying of sweet pepper and garlic using the tunnel GH drier.

In this case, a linear correlation between the temperature difference $T_{ig} - T_a$ and the radiation I is obtained according to Eq. (4). In Fig. 5, experimental values for this relation are shown for the 10 days, showing there is an origin ordinate around 0.25C due to the thermal inertia of the GH solar drier. This inertia changes slightly the linear behavior, particularly when the

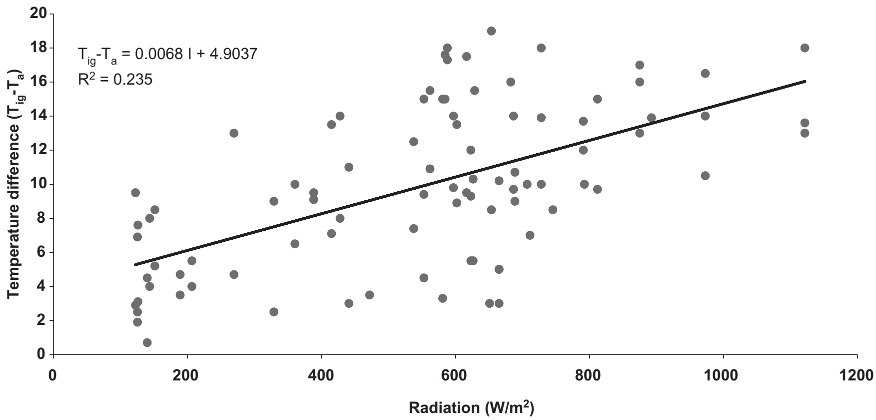

FIG. 5. THE LINEAR CORRELATION BETWEEN SOLAR RADIATION AND THE DIFFERENCE BETWEEN GREENHOUSE TEMPERATURE AND AMBIENT TEMPERATURE ($T_{ig} - T_a$)

radiation is low. Nevertheless, if a linear regression passing through the origin is adopted, the linear equation is:

$$T_{ig} - T_a = 0.0068\,I + 4.9037 \tag{6}$$

where T_{ig} is the air temperature inside GH, C; T_a is the ambient air temperature, C; and where the value for the coefficient of determination R^2 is 0.235 which is not a good fit of linear correction due to lot of deviation from the line.

In Fig. 6, experimental values for this relation are shown for 10 days. RH inside GH was some time more then the ambient and visa versa because of low moisture in air but high moisture release by soil during nighttime, which changes slightly the behavior, particularly when the radiation is low in the morning. Nevertheless, if a regression passing through the origin is adopted, the linear equation is:

$$H_{Rig} - H_{Ra} = 0.0078\,I - 1.897 \tag{7}$$

where H_{Rig} is the air RH inside GH, %; H_{Ra} is the ambient air RH, %; and where the value for the coefficient of determination R^2 is 0.0556 which is not a good fit of linear correction due to lot of deviation form the line.

Solar radiation varies extremely in India and hence, the fit was not good. Solar radiation varied from 123 W/m^2 in the morning to 1,121 W/m^2 at noon during the experimentation. Kadam and Samuel (2006) have reported similar results.

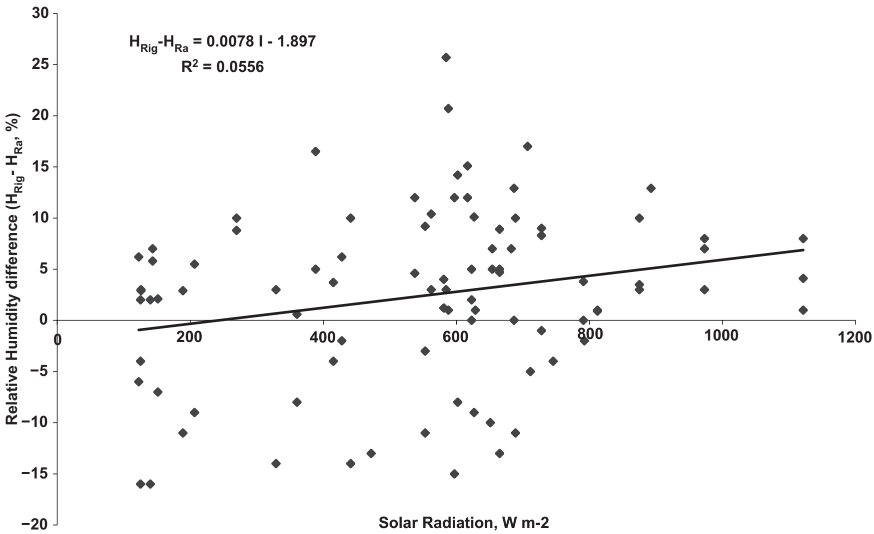

FIG. 6. THE LINEAR CORRELATION BETWEEN SOLAR RADIATION AND THE DIFFERENCE BETWEEN GREENHOUSE AND AMBIENT RH ($H_{Rig} - H_{Ra}$)

Air Temperature Inside and Outside GH

The relationship between ambient (T_a) and inside GH (T_{ig}) air temperature of GH was studied and a linear correlation between inside and outside GH air temperature was plotted in Fig. 7:

$$T_{ig} = 1.8064\,T_a - 18.345 \tag{8}$$

with a value for R^2 of 0.7921.

Air RH Inside and Outside GH

The relationship between ambient (RH_a) and inside GH (RH_{ig}) air RH for the GH as solar heat collector was studied and a linear correlation between ambient and inside GH air RH was plotted in Fig. 8:

$$H_{Rig} = 0.8733\,H_{Ra} - 2.4398 \tag{9}$$

with a value for R^2 of 0.9205.

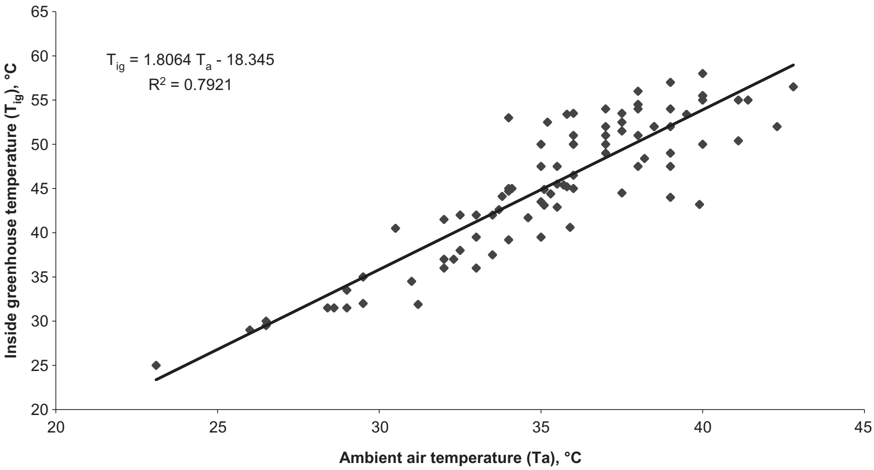

FIG. 7. RELATION BETWEEN AMBIENT AND INSIDE GREENHOUSE AIR TEMPERATURE (C)

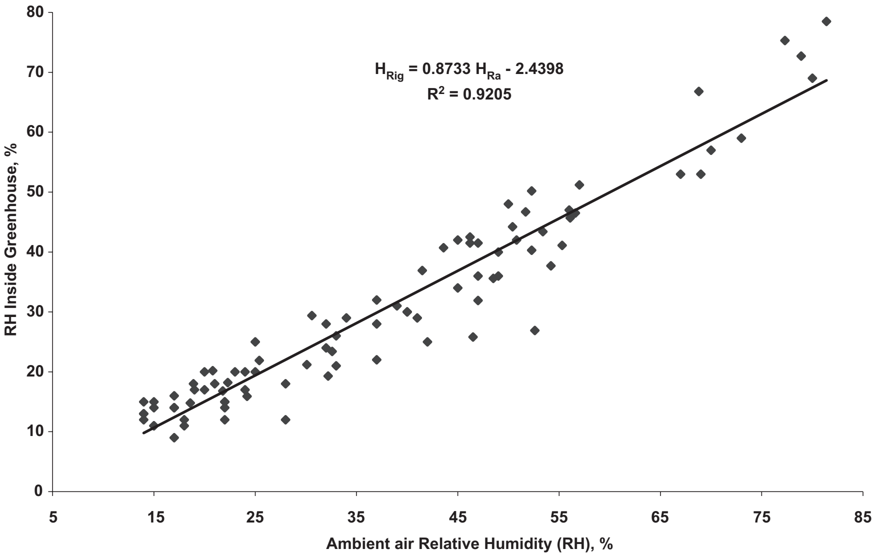

FIG. 8. RELATIONSHIP BETWEEN AMBIENT AND INSIDE GREENHOUSE RH (%)

Pretreatments

There was not much effect of pretreatment on drying characteristics of 3 mm sliced onion. All samples, irrespective of preservatives, took 19 h (under the sun) to bring down the moisture content to 5.79 ± 0.502% (w.b.) from 86.07% (w.b.).

It was found that preservative had a significant effect (probability, $P < 0.05$) on dehydration ratio of onion slices. Dehydration ratio is the amount of water present in fresh product to the amount of water present in dehydrated product or simply, it is the ratio of the weight of the fresh sample (B), used for drying, to the weight of the dehydrated sample (A) and is presented in Table 1.

$$DR = \frac{B}{A} = B : A \tag{10}$$

Maximum and minimum dehydration ratios were 11.49:1 (fresh onion slice : dried) in 0.75% NaCl and 10.54:1 in control, respectively. An increase in the dehydration ratio indicates a decrease in moisture content, which is an improvement only if the shrinkage ratio is less.

Moisture Removed and Drying Curve

Relationship between moisture removed from onion slices and drying time with respective to preservatives (KMS and NaCl preservatives) at different concentration has been presented in Fig. 9. It is apparent that moisture decreases continuously with drying time. There was no constant rate period but falling rate period was observed. This clearly indicates that diffusion is the dominant physical mechanism governing moisture movement in the sample. Similar results were obtained by different authors on drying of various fruits and vegetables such as apricots, grapes, mulberries and cauliflower (Raouzeos and Saravacos 1986; Vagenas and Marinos-Kouris 1991; Doymaz and Pala

TABLE 1.
EFFECT OF PRESERVATIVE AND ITS CONCENTRATION ON DEHYDRATION RATIOS OF ONION SLICES

Preservative	Concentration level (%)				SD	$CD_{0.05}$	CV	Both preservative		
	0.75%	0.50%	0.25%	Control				SD	$CD_{0.05}$	CV
KMS	11.22	11.29	11.21	10.54	0.0596	0.3373	1.62	0.0885	0.5271	2.72
NaCl	11.49	11.25	11.99	10.78	0.11	0.7379	3.44			

KMS, potassium meta-bisulphite; CV, coefficient of variation.

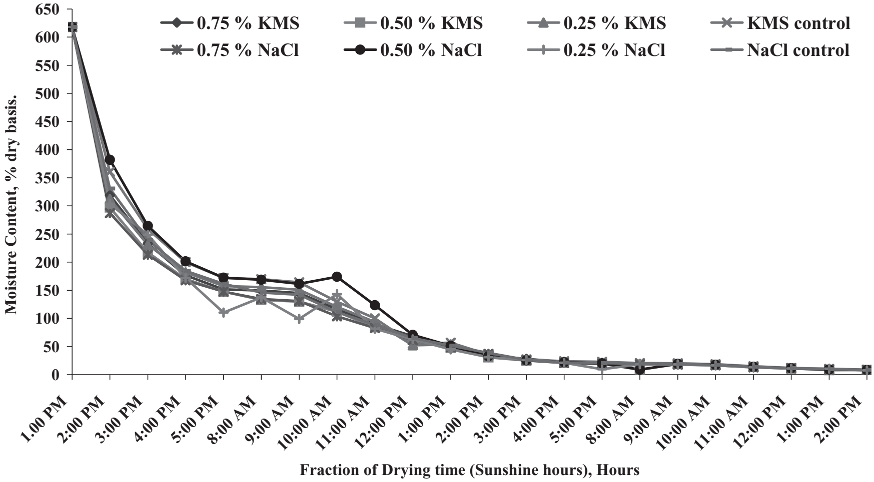

FIG. 9. RELATIONSHIP BETWEEN MOISTURE CONTENT (%d.b.) OF ONION SLICES AND DRYING TIME INSIDE GREENHOUSE

2003; Doymaz 2004; Kadam and Samuel 2006). The lowest water removed was 90.515% in control samples and maximum water removed was 91.295% in 0.75% NaCl samples after 19 h of GH drying.

Drying rate curve was plotted as drying rate ($dM/d\theta$) versus time, θ in h to get clearly the constant and falling rate phases (Figs. 10 and 11). Drying constant was not observed during first 3–4 h but it was observed between 4 to 6 h after drying process began, and then falling rate phase was noticed.

CONCLUSIONS

The experiment was carried to study the drying of onion slices using low-cost GH during summer season. Low-cost GH structure can be utilized for drying the crops during summer when it is unfit for growing crops. Pretreated onion slices took around 19 sunshine hours for drying. Thermal efficiency of the GH dryer was about 20.82%, which directly depends on solar radiation and humidity in the air. Preservatives were found to be significantly different (probability, $P < 0.05$ and pretreatment of potassium metabisulphite @ 0.50% was found to be the best). However, moisture ratio, drying time and drying rate curves were not dependent on the preservative used as a pretreatment.

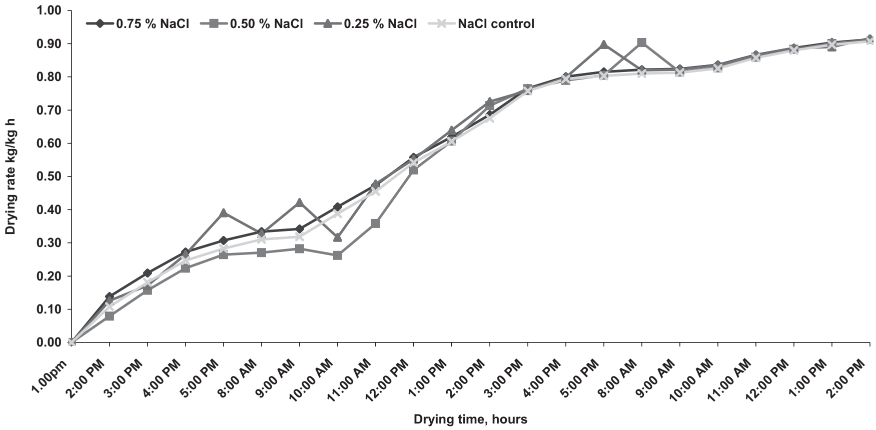

FIG. 10. DRYING RATE CURVE OF ONION SLICES DURING GREENHOUSE DEHYDRATION PROCESS (NaCL PRETREATMENT)

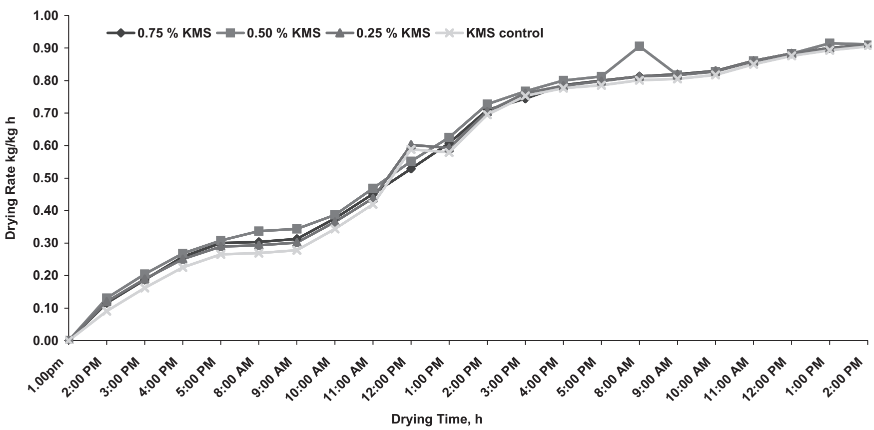

FIG. 11. DRYING RATE CURVE OF ONION DURING GREENHOUSE DEHYDRATION PROCESS (KMS PRETREATMENT)

NOMENCLATURE

A_s	surface area of greenhouse heat collector, m^2
C_p	air specific heat, KJ/kg/C
F_R	heat removal factor
H_{Rig}	air relative humidity inside greenhouse, %
H_{Ra}	ambient air relative humidity, %
I	solar radiation, W/m^2
K	drying constant
M	moisture content at time θ, % d.b.
m_a	air mass flow rate, kg/s
M_e	equilibrium moisture content, % d.b.
M_o	initial moisture content, % d.b.
M_R	moisture ratio
T_a	ambient temperature, C
T_{ig}	air temperature inside greenhouse, C
θ	time, h
α	collector mean absorption coefficient
η	instantaneous efficiency, %
τ	transmittance of the cover

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