Journal of Current Research in Food Science 2021; 2(2): 44-56

E-ISSN: 2709-9385
P-ISSN: 2709-9377
JCRFS 2021; 2(2): 44-56

www.foodresearchjournal.com
Received: 25-05-2021
Accepted: 27-06-2021

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Drying kinetics and effects of different drying methods on nutritional quality of raw and differently blanched green peas

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DOI: https://doi.org/10.22271/foodsci.2021.v2.i2a.44

Abstract
The study was done to analyze the effects of various blanching conditions on nutritional quality of differently dried green peas using three different methods namely, open sun drying, cabinet drying and drying in solar dehydrator. Samples were analyzed for various parameters such as, moisture content, rehydration ratio, linear shrinkage ratio, green color ratio, total chlorophyll, ascorbic acid, microbial load and sensory analysis. Various mathematical models were used to study the drying behavior of green pea samples. With the help of various statistical parameters, the best model for different drying conditions was found out. Chemically blanched peas dried in cabinet dryer were considered best among all the treated peas dried under different drying conditions and least acceptance was given to un-blanched open sun dried peas. Quality and acceptability of solar dried peas were higher than open sun drying but lower than cabinet drying. While considering models, Logarithmic model gave a very good performance on all the statistical parameters. So, it can be used to predict the drying behavior of green peas.

Keywords: drying kinetics, green peas, blanching, mathematical models, statistical parameter

1. Introduction

Drying is one of the oldest food preservation technique. Preservation of vegetables and fruits is important for keeping them shelf stable for longer period. Numerous process technologies are in use to preserve food products; freezing, canning, dehydration etc. Drying of solids means removal of relatively small amount of water or other liquids to an acceptable level using different temperature and RH conditions (Cheng W M, 2006). Drying is an effective way of preservation for reducing postharvest losses and equalizing shortages in supply (Liberty, Okonkwo, & Ngabea, 2014) [16]. Severe losses in quantity and quality of dried product are observed due to open sun drying under hostile climatic conditions (Pangavhane, Sawheny, & Sarsavadia, 2002) [20]. These losses are due to contamination by dust, dirt and invasion by insects, rodents or animals available in open environment. Thus, use of solar dryers can reduce crop losses and improve overall quality if compared with conventional methods such as sun or shade drying (Yaldiz, Erteken, & Uzun, 2001) [38]. Pea, *Pisum sativum* is a leguminous vegetable of much importance and is consumed in several forms such as fresh green peas, processed canned peas, dehydrated peas and de-husked splits. These are thought to be originated near Afghanistan in southwest Asia. Although the ancestral pea is extinct (Weaver & Woys, 2003) [37]. Green peas are good source of protein, starch and fibers. These are also good in many essential B-complex vitamins such as pantothenic acid, thiamin, niacin, and pyridoxine and minerals such as calcium, copper, iron, manganese and zinc (Rudrappa & Umesh, 2009) [23]. Green peas are perishable with 78% moisture and seasonal in nature. This perishability along with seasonal availability and regional abundances are the major reasons for its preservation (Jadhav, Visavale, Sutar, Annapure, & Thorat, 2010) [11].

The objectives of this study were to study the impact of different drying conditions on the properties of raw and differently blanched green peas and apply various drying models to predict the best suitable model for process dynamics of green pea drying system. Drying deteriorates heat labile vitamins. Physical pre-treatment (blanching) prior to convective drying is an option to obtain good quality dried fruit and vegetables with improved drying kinetics. Pre-treatment reduces drying period by increasing drying rate (Kingsly R P, 2007)

[13]. Potassium metabisulfite used for pretreatment of green leafy vegetables reduced loss of ascorbic acid, a heat labile vitamin (Mulay, Pawar, Thorat, Ghatge, & Ingle, Effect of pretreatments on quality of dehydrated cabbage, 1994) [18]. Mathematical model is a description of a system using mathematical language. Models describe our thinking about how the world functions. In mathematical modeling, we transform those beliefs into the language of mathematics. Mathematical modeling is a good tool for understanding and controlling the process (Severo, Gusberti, & Pinto, 2005) [24]. The most important feature of drying technology is process modeling, simulation for the design of drying equipment and to establish best possible operating conditions to enhance the efficiency of drying facility (Murthy K. T., Harish, Rashmi, Mathew, & Monisha, 2014) [19]. Drying kinetics of all food materials cannot be described by same equation because of differences in moisture and transport phenomenon during dehydration. There have been many studies on the effect of pre-treatment on drying kinetics of fruits and vegetables (Krokida, Karathanos, Maroulis, & Kouris, 2003) [14]. In current study, nine drying models i.e. Newton, Henderson and Pebis, Page, Overhults, Wang and Singh, Logrithmic two term, two term exponential and Verma have been used. These models were used previously for various crops like peas, coriander and tomato (Jadhav, Visavale, Sutar, Annapure, & Thorat, Studies on Solar Cabinet Drying of Green Peas, 2010) [11], (Silva, Lima, Silva, Almeida, & Gomes, 2008) [27], (Taheri-Garavanda, Rafieea, & Keyhani, 2011) [32].

2. Materials and Methods

2.1 Pre-treatments and drying procedures

Green peas were procured from local market, Hisar and cleaned and washes thoroughly. Blanching was done under two different conditions; water blanching at 100ºC for 4min and water with 0.5% potassium metabisulphite+0.1% magnesium oxide+0.1% sodium bicarbonate blanching at 100ºC for 4 min followed by immediate cooling in ice water for 2min and air drying. Peas to solution ratio was 1:5. Raw and pre-treated peas were then dried using sun drying, solar drying and cabinet drying methods. For drying, 100gm sample was kept in each round tray of 150cm diameter. For open sun drying, sample trays were left for drying under open sun at 35.6 -47.2ºC temperature and 11-22% relative humidity. In solar drying, solar dehydrator was placed in solar light one hour before drying, angle of reflecting mirror was adjusted according to sun position and drying was done at 41.9-64.4 ºC temperature and 18-35% relative humidity. An exhaust fan was attached with dryer to evacuate excess moisture. For cabinet drying, sample trays were kept in pre-heated dryer at 55 ºC temperature and 10-12% relative humidity. Temperature and humidity were measured using digital thermo-hygrometer. During nights, samples were stored in refrigerator in air tight low density polyethylene bags and drying was continued in the next day. Drying of the samples was continued until the moisture content reached 5% (w.b.). During drying, weight of sample was recorded at regular intervals. Dried samples were packed in low density polyethylene and stored in refrigerator at 4-5 ºC.

2.2 Analytical procedures for studying drying behavior

2.2.1 Moisture content

Moisture content was determined using the hot air oven method at 100 ˚C till the constant weight was obtained (Ranganna, Handbook of analysis and quality control for fruit and vegetable products., 1986) [22].

2.2.2 Moisture ratio (MR)

Moisture ratio was calculated as per the method described by Menges *et al.* (Menges & Ertekin, 2006) [17].

2.2.3 Process dynamics and modeling of peas drying

Temperature independent parameters and moisture dependent parameters such as drying time, drying rate and moisture ratio were used to study process dynamics. Various models related to these variables were studied and mathematical relationships were developed. These models were investigated for describing the drying characteristics along with their drying constant and other constants. Various linear and non-linear regression models are important tools to find the relationships between different variables. The differences between MR Predicted and MR Experimental were determined and statistical parameters such as coefficient of determination (R^2), reduced chi square (χ^2), root mean square error (RMSE), mean bias error (MBE) were used to evaluate the performance of models. These parameters were then used to compare the performance of different models and determine the goodness of fit. These models are listed in Table 1.

Table 1: Mathematical models applied to study the process dynamics of drying.

Sr. No.	Model name	Model equation	References
1	Newton model	$MR = e^{-kt}$	(Sunil V. N., 2013) [31]
2	Henderson and Pabis model	$MR = ae^{-kt}$	(Sunil, Varun, & Sharma, 2013) [31]
3	Page model	$MR = e^{-kt^n}$	(Zhang & Litchfleld, 1991) [39]
4	Overhults model	$MR = e^{-(kt)^n}$	(Sunil, Varun, & Sharma, 2013) [31]
5	Wang and Singh model	$MR = 1 + at + bt^2$	(Wang & Singh, 1978) [36]
6	Logarithemic model	$MR = ae^{-kt} + c$	(Togrul & Pehlivan, 2003) [33]
7	Two-term model	$MR = a\, e^{(-kt)} + b\, e^{(-gt)}$	(Glenn, 1978) [6]
8	Two-term exponential model	$MR = a\, e^{(-kt)} + (1-a)\, e^{(-kat)}$	(Sharaf-Eldeen, Blaisdell, & Hamdy, 1980) [25]
9	Verma model	$\mathrm{MR = a\, e^{(-kt)} + (1-a)\, e^{(-gt)}}$	(Verma, Bucklin, Ednan, & Wratten, 1985) [35]

2.2.4 Performance evaluation of models

Primary criteria for the selection of best model was considered as coefficient of determination (R^2). Higher R^2 value, closer to 1 represented the best fit of model (Gunhan & Hepbasli, 2005) [8]. Reduced chi-square (χ^2), root mean square error (RMSE), mean bias error (MBE) between observed and predicted variables accounted for variation in moisture ratio of dried samples (Goyal, Mujjeb, & Bhargava, 2008) [7]. The equations with highest R^2 and lowest MBE and RMSE were chosen to better estimate the drying curves and these statistical values were calculated as;

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(MRexp_i - MRpre_i)^2}{\sum_{i=1}^{n}(MRexp\ mean - MRpre_i)^2}$$

$$\chi^2 = \frac{\sum_{i=1}^{n}(MRexp_i - MRpre_i)^2}{N - n}$$

$$RMSE = [\frac{1}{N}\sum_{i=1}^{n}(MRpre_i - MR_{exp\ mean})^2]^2$$

$$MBE = \frac{1}{N}\sum_{i=1}^{n}(MRpre_i - MRexp_i)^2$$

Where, $MRexp_i$ was 1th experimental moisture ratio, $MRpre_i$ was 1th predicted moisture ratio, N was number of observations, z was number of constant in drying model and $MR_{exp\ mean}$ was mean value of experimental moisture ratio. Non-linear regression software package named XLSTAT was used for data analysis.

2.2.5 Drying rate (DR)
Drying rate was calculated as;

$$DR = \frac{W_i - W_d}{t \times W_i}$$

Where, W_i was initial weight of sample, t was drying time and W_d was dry weight of sample.

2.2.6 Efficiency of dryer
Efficiency of dryer (solar dryer vs. cabinet dyer/open sun drying) was calculated as;

$$\text{Dryer efficiency} = \frac{W_i - W_d}{W_i} \times 100$$

Where, W_i was initial weight of sample and W_d was weight of dried sample.

2.3 Analytical procedures for studying effects on quality of raw and pre-treated dried peas
2.3.1 Moisture content
Moisture content was determined as per the method already discussed in section 2.2.

2.3.2 Rehydration ratio (RR)
Rehydration ratio was measured according to method specified in Indian Standards (ISI, 1978) [10].

2.3.3 Linear Shrinkage Ratio (LSR)
LSR was calculated as the ratio of longest dimension before and after drying (Giri & Prasad, 2006) [5]. The longest dimension of 20 randomly selected peas were measured by a digital caliper and LSR was calculated.

2.3.4 Green Color Ratio (GCR)
GCR was measured by a Hunter Lab spectro-colorimeter (Model Mini Scan XE plus 45=O-L). The relative a* value was taken as an indicator of loss of green color and expressed as;

$$\text{Green color ration} = \frac{\text{Hunter Lab } a^* \text{ value of dried peas}}{\text{Hhunter Lab } a^* \text{ value of fresh peas}} \times 100$$

2.3.4 Ascorbic acid
Chemical method used was based on reduction of 2, 6-dichlorophenol-indophenol and ascorbic acid in mg/100g was calculated (Ranganna, Handbook of analysis and quality control for fruit and vegetable products, 1986) [22].

2.3.5 Total chlorophyll
Total chlorophyll was quantified using a spectrophotometric method based on Beer-Lambert's law (Srivastava & Kumar, 2002) [30].

2.3.6 Total aerobic microbial count
Total viable count was estimated by pour plate method after dilution so that the plate count did not exceed 300 colony forming units. One ml of 10^{-4}, 10^{-3}, 10^{-2} dilution were transferred to sterile petri-plates. Molten sterilized agar medium of about 10-15 ml/plate was added. Control plates of sterilized media were also prepared. Prepared petri-plates were incubated at 30 °C for 24-48hr in BOD incubator (Commission, 2007) [3].

$$\text{Total aerobic microbial count} = \text{No. of colonies counted} \times \text{Dilution factor}$$

2.3.7 Sensory analysis
Sensory evaluation was carried out by a panel of 9 semi-trained judges using Hedonic rating test, usually conducted to measure the consumer acceptability of food products (Ranganna, Handbook of analysis and quality control for fruit and vegetable products., 1986) [22].

2.4. Statistical analysis
All qualitative tests of peas were conducted in three replicates. All values observed were expressed as mean values ± standard deviation. The analytical tools provided in the MS Office 2007 were used to prepare the tables, graphs and to analyze variance (ANOVA).

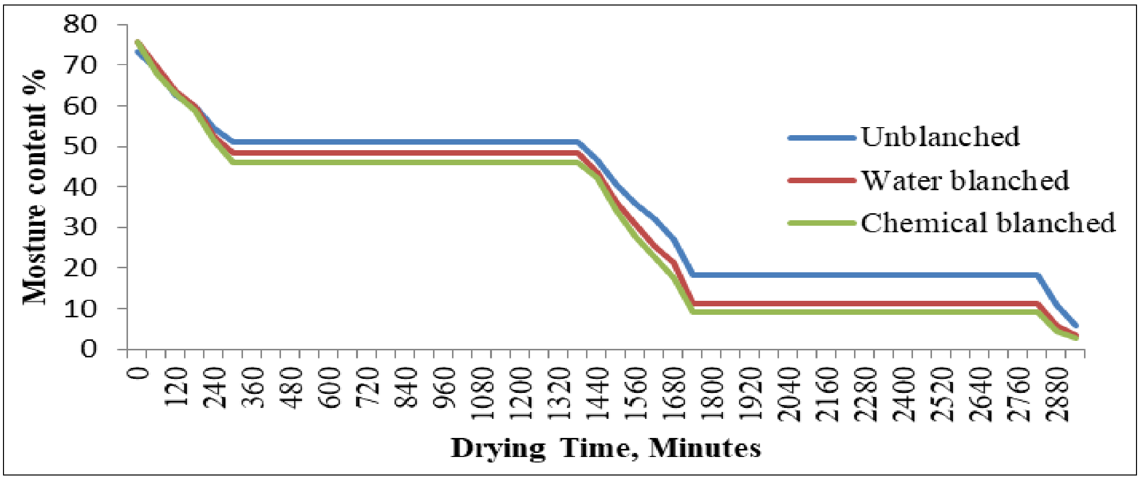
3. Results and Discussion
3.1 Drying behaviour of peas
3.1.1 Drying curve
Full design layout of peas drying with the observed temperature and relative humidity is presented in Table 2. Drying curves of various drying processes used are presented in Figure 1. The relationship between moisture content (% wet basis) and drying time during drying under open sun stated that the moisture content decreased with increase in drying time. Loss of moisture was very quick in the beginning and slowed thereafter. Total time required to dry pea samples under open sun drying was 2940min including two dark periods. So, actual drying time to dry 100g green pea sample under open sun was 780min. Un-blanched samples showed maximum resistance to moisture removal as compared to both blanched samples. Krishna Murthi *et al.* also reported that blanching reduced drying time by relaxing tissue structure and yielded good quality dried products, which reflected reduced energy requirement for dehydration (Murthy, Harish, Rashmi, Mathew, & Monisha, 2014) [19].

In cabinet drying, total time required to dry sample at 55ºC was 1740min with dark period of 1080min. Actual drying time to reduce moisture content to as low as 5% was 660min. The relationship between moisture content and drying time during drying in cabinet dryer showed that blanched peas took lesser time to reach the same level of moisture content as compared to un-blanched sample. Similar results were also observed by Turhan *et al.* who reported that convective drying combined with blanching increased drying rate for food products such as apples and peaches (Turhan, Turhan, & Sahbaz, Drying Kinetics of Red Pepper, 1997) [34].

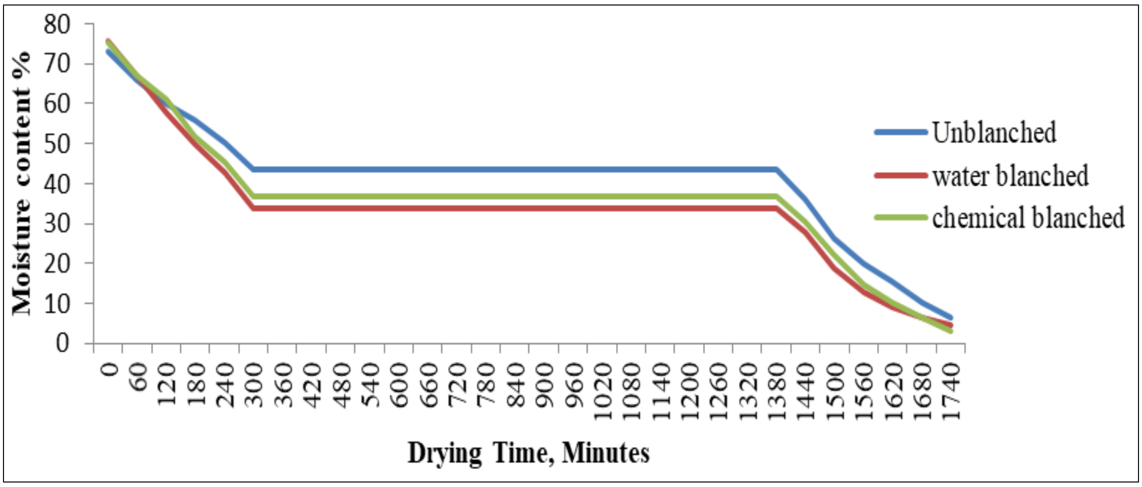
Solar dehydrator took 1680min in total to dry pea samples with a dark period of 1080min. Actual drying period to dry samples to about 5% moisture content was 600min The relationship between moisture content and drying time showed that un-blanched green pea samples had more resistance to drying. Drying using solar dryer was fast in comparison with cabinet dryer and open sun drying because of highest temperate conditions attained in solar dryer. Earlier studies by Singh *et al.* stated that higher the temperature lesser will be the time required for drying (Singh, Kawatra, Sehgal, & Pragati, 2003) [28].

Table 2: Temperature and Relative Humidity during drying process.

Days	Time	Open sun drying		Cabinet drying		Solar cabinet drying	
	(Hours)	Temperature (°C)	Relative Humidity (%)	Temperature (°C)	Relative Humidity (%)	Temperature (°C)	Relative Humidity (%)
Day 1	1	39.3	22	55.1	12	48.3	35
	2	43.6	16	55.0	11	56.7	25
	3	47.2	13	55.2	10	64.4	21
	4	45.6	13	55.0	10	58.1	20
	5	45.2	12	55.0	10	52.6	18
	Dark period (night time)						
Day 2	6	35.6	18	55.0	11	41.9	38
	7	40.2	14	55.0	10	46.9	35
	8	45.8	13	55.1	10	54.4	28
	9	46.7	11	55.1	10	61.3	19
	10	45.3	12	55.0	10	59.1	22
	11	42.4	12	55.0	10	-	-
	Dark period (night time)						
Day 3	12	36.3	20	-	-	-	-
	13	40.6	17	-	-	-	-



(a)



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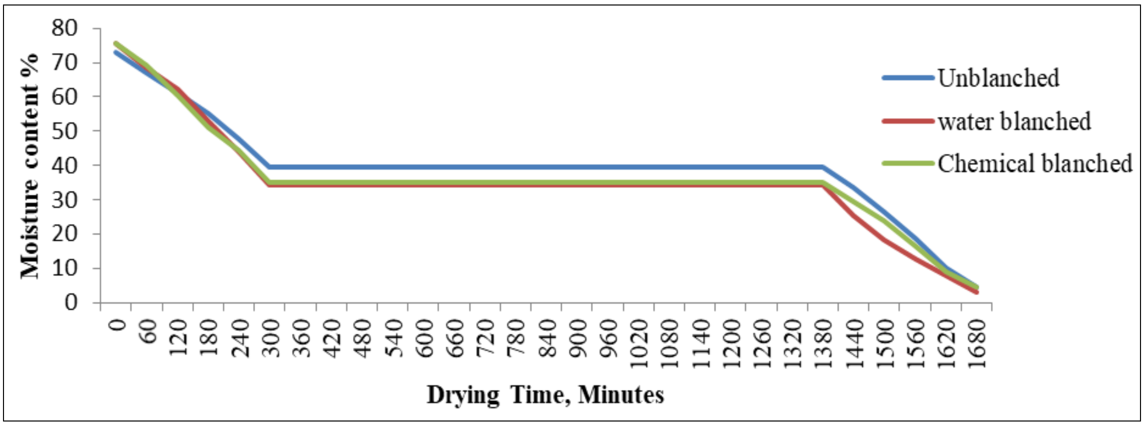

(c)

Fig 1: Drying curves of raw and pre-treated peas samples. (a) Open sun drying, (b) Cabinet drying and (c) Solar drying.

3.1.2 Drying rate

Results of drying rate after various drying methods are presented in Table 3. Graph of drying rates of peas samples is represented in Figure 2. Maximum drying rate of 0.298 was observed in the case of water blanched solar dried samples followed by chemically blanched solar dried peas (0.2903) and chemically blanched cabinet dried peas (0.268). Minimum drying rate of 0.1918 was found in drying of un-blanched samples dried under open sun. There was no significant difference among the values of drying rate for differently treated samples dried under different drying conditions. Similar results were reported by Piga *et al.* that blanched vegetables required shorter drying time as compared to untreated samples (Piga A., Pinna, Ozer, Agabbio, & Aksoy, 2004) [21]. As per this study, effect of the type of dryer on drying rate of samples was more as compared to the pretreatments.

Table 3: Drying rates of raw and pre-treated peas dried using different drying methods.

Treatments	Open sun drying	Cabinet drying	Solar drying
Un-blanched	0.1918±0.004	0.2255±0.007	0.2558±0.003
Water blanched	0.2269±0.001	0.2639±0.005	0.2974± 0.0004
Chemically blanched	0.2283±0.0007	0.2680±0.005	0.2903±0.003

Uses Harmonic Mean Sample Size = 3.000, Values are mean ±SD, n=3, $P < 0.05$.

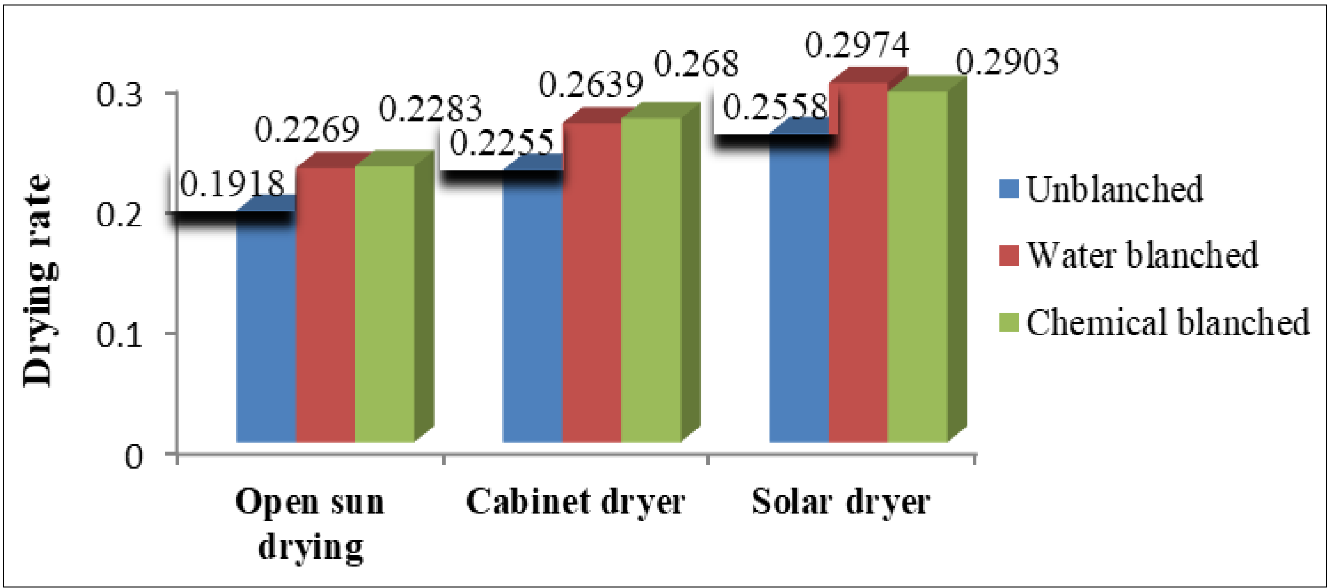

Fig 2: Drying rate of raw and pre-treated peas dried using different drying methods

3.1.3 Efficiency of drying processes

Results of drying efficiencies of various drying methods for raw and pre-treated peas are presented in Table 4. Graph of drying efficiency of peas samples is shown in Figure 3. Efficiency of all drying methods for un-blanched samples was minimum. There was no significant difference between the values of drying efficiency for differently treated samples dried in different dryers. According to this study, there was no significant difference between the drying efficiencies in case of samples dried using different dryers. Effect of the type of dryer on drying efficiency was less as compared to the effects of pretreatments.

Table 4: Drying efficiency of different drying methods for raw and pre-treated peas.

Treatments	Open sun drying	Cabinet dryer	Solar dryer
Unblanched	66.9955±1.4160	66.6544±2.3406	66.6544±0.8520
Water blanched	72.1209±0.4393	71.0321±1.6553	72.7169±0.1141
Chemically blanched	72.7506±0.2381	72.2673±1.5465	71.1585±0.9496

Uses Harmonic Mean Sample Size = 3.000, Values are mean ±SD, n=3, P < 0.05.

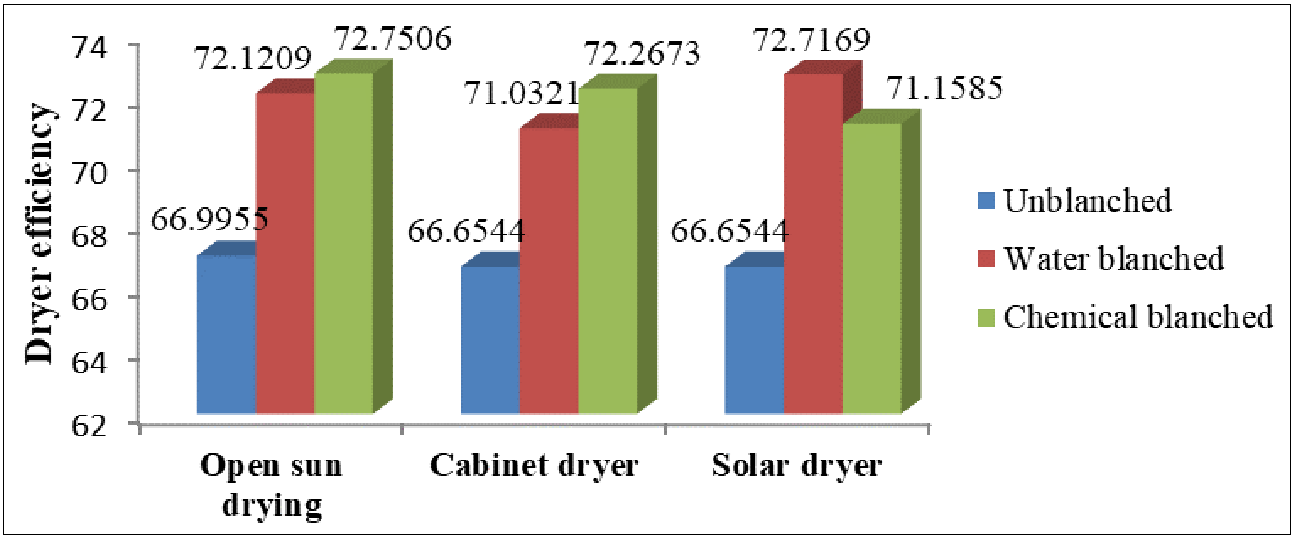

Fig 3: Drying efficiency of different drying methods for raw and pre-treated peas.

3.2 Evaluation of raw and pre-treated dried peas
3.2.1 Moisture content
The results of moisture levels of raw and pre-treated peas before and after drying are presented in Table 5. Moisture content of raw sample was 73.13% which increased to 75.55% and 75.49% after water blanching and chemically blanching, respectively due to water absorption during blanching. Average moisture content after dehydration was 5.59% in case of un-blanched sample, 3.59% in case of hot water blanched sample and 3.44% in case of blanching with chemicals. Blanching affected the firmness of food product. Selective permeability of cell membrane was affected and moisture removal from food was facilitated after blanching (Lewicki & Piotr, 1998) [15]. Minimum moisture content was achieved in case of chemically blanched sample dried using solar dryer. This might be due to the 8-10ºC higher temperature attained in solar dehydrator.

Table 5: Moisture levels of raw and pre-treated peas before and after drying.

Treatment	Moisture content before drying (g/100g)	Moisture content after drying (g/100g)
Un-blanched	73.1394±0.4879	5.5913±1.073
Water Blanched	75.5532±0.447	3.5972±0.853
Chemically Blanched	75.4934±0.5641	3.4484±0.813

Uses Harmonic Mean Sample Size = 3.000, Values are mean ±SD, n=3.

3.2.2 Rehydration ratio
The results of rehydration ratio of raw and pre-treated dried peas are presented in Table 6. It was found to be a complex function of product permeability, compactness and density (Sharma & Prasad, 2001) [26]. Rehydration ratio of 3.49 was maximum in cabinet dried samples blanched in water with chemicals and followed by rehydration ratio of 3.15 achieved in chemically blanched dried in solar dryer. Because moisture removal in solar dryer and cabinet dryer was fast as compared to open sun drying. A positive effect of chemically blanching was observed on rehydration ratio in all the three drying procedures. Water blanched samples had higher value of rehydration in comparison with un-blanched but lower than the values of chemically blanched samples. Minimum rehydration ratio was observed in case of un-blanched samples dried under open sun. The results obtained in present study were in accordance with studies reported by Sunil *et al.* who concluded that rehydration capacity of the green peas dried in solar dryer was higher than the peas dried under open sun (Sunil, Varun, & Sharma, Modelling the drying kinetics of green peas in a solar dryer and under open sun, 2013) [31]. There was significant difference among the rehydration ratio of samples dried in different dryers. There was significant difference among the rehydration ratio of samples dried after different pre-treatments. Dependence of rehydration ratio on blanching treatments was higher in comparison with the effects of drying methods.

3.2.3 Linear Shrinkage Ratio
The results of linear shrinkage ratio of raw and pre-treated dried peas are presented in Table 6. The linear shrinkage ratio of un-blanched sun dried peas was 66.16%. Mean linear dimension of fresh peas was found to be 9.60mm and the linear shrinkage ratios for the dehydrated peas varied from 63.76% to 70.13%. Maximum LSR was observed in water blanched samples dried in cabinet dryer followed by chemically blanched samples dried in cabinet dryer. Minimum LSR was observed in chemically blanched samples dried under open sun. There was no significant

deference among the values of linear shrinkage ratios of peas dried in different dryers. There was no significant difference in LSR of differently treated samples of green peas dried in solar dryer, cabinet dryer and dried under open sun. In a vacuum assisted microwave drying study of green peas carried out by Srivastava *et al.* it was reported that LSR for dehydrated peas varied between 71.2% and 85.7%. At higher temperatures, drying rates were higher due to the generation of more heat at greater depths, resulting in escape of water vapor at a faster rate without causing much collapsing in the cellular structure of peas (Srivastava & Chauhan, Optimizing Drying Conditions for Vacuum-Assisted Microwave Drying of Green Peas (Pisum sativum L.), 27:6,, 2009) [29].

3.2.4 Green color ratio

The results of green color ratio of raw and pre-treated dried peas are presented in Table 6. The green color of peas is due to the presence of chlorophyll pigments within the cells. The chromacity coordinate a* of the HUNTERLAB measured the amount of red and green colors of the samples, which was most relevant parameter in case of green peas (Alves-Filho, Garcia-Pascual, Eikevik, & Strommen, 2004) [1]. The a* value for fresh green pea sample was -11.22. Maximum GCR of 60.36% was observed in chemically blanched cabinet dried samples followed by 44.83% in cabinet dried water blanched samples. Lowest green color ratio of -8.49% was observed in un-blanched open sun dried samples. There was significant difference among the GCR of samples dried in different dryers. There was no significant difference in the GCR of differently treated samples. In a study on freeze drying of green peas, Alves-Filho *et al.* reported that the retention of green color was higher in peas dried at lower temperatures (Alves-Filho, Garcia-Pascual, Eikevik, & Strommen, 2004) [1].

3.2.5 Ascorbic acid

The results of ascorbic acid of raw and pre-treated dried peas are presented in Table 6. The ascorbic acid content of un-blanched fresh green pea sample was 121.11mg/100gm which was reduced to 101.6mg/100gm in case of water blanching and 110.1mg/100gm in case of chemical blanching. Gupta *et el.* studied the effects of pre-treatments on retention of ascorbic acid in green leafy vegetables such as fenugreek, *brahmi* and *bathua* and found similar decreasing pattern of after blanching (Gupta, Laxmi, & Prakash, 2008) [9]. After dehydration, maximum ascorbic acid retention was observed in cabinet dried un-blanched samples with 76.37mg/100gm followed by 63.87mg/100g in chemically blanched samples dried in cabinet dryer. Minimum ascorbic acid content of 35.53mg/100gm was reported in water blanched samples dried in solar dryer. There was significant difference among the ascorbic acid contents of samples dried in different dryers. But, there was no significant difference in the ascorbic acid contents of differently treated samples. Drying temperatures significantly affected the ascorbic acid content of green pea samples. This study showed decrease in Vitamin C in all of the differently treated dried samples as Vitamin C is a heat labile vitamin and is destroyed when exposed to direct sunlight and heat due to oxidation (Gupta, Laxmi, & Prakash, 2008) [9].

3.2.6 Total chlorophyll

The results of chlorophyll content in raw and pre-treated dried peas are presented in Table 6. Maximum chlorophyll retention of 29.13mg/100g was found in chemically blanched samples dried in cabinet dryer followed by 26.55mg/100g in chemically blanched solar dried samples. Minimum chlorophyll retention was observed in un-blanched open sun dried samples. Initial chlorophyll content of fresh green pea was 71.18mg/100g which was decreased to 62.34mg/100g in case of water blanching and 67.34mg/100g in case of chemical blanching. There was significant difference among the total chlorophyll content of samples dried in different dryers. There was also significant difference among the total chlorophyll content of samples dried after different pre-treatments. Dependence of total chlorophyll content on blanching treatments was more as compared to drying methods.

3.2.7 Microbial load

The results of chlorophyll content in raw and pre-treated dried peas are presented in Table 6. Microbial load of fresh pea sample was 16×10^4cfu/g. Maximum microbial load of 147×10^4 cfu/g was observed in un-blanched open sun dried sample followed by 99×10^4cfu/g in water blanched open sun dried samples due to direct exposure to environment and dirt. Minimum microbial contamination of 48×10^4cfu/g was observed in chemically blanched samples dried in solar dehydrator. Microbial load in open sun dried samples was higher as compared to the microbial load of samples dried in cabinet dryer and solar dryer. In solar dryer microbial contamination was low due to isolation form outer environment and higher temperature attained in comparison to cabinet dryer and open sun drying. There was significant difference among the microbial load of samples dried in different dryers. There was also significant difference in the microbial load of samples dried after different pre-treatments. The dependence of microbial load on drying methods was more as compared to blanching treatments.

Table 6: Results obtained from evaluation of raw and pre-treated dried peas.

Treatments Drying method	Un-blanched (control)	Water Blanched	Chemically Blanched
Rehydration Ratio (g/100g)			
Open Sun Drying	1.68±0.08	2.44±0.12	2.58±0.18
Cabinet Drying	2.34±0.15	3.01±0.09	3.49±0.04
Solar Drying	2.07±0.22	2.88±0.14	3.15±0.08
Linear Shrinkage Ratio (%)			
Open Sun Drying	66.16	64.06	63.76
Cabinet Drying	64.83	70.13	69.69
Solar Drying	63.91	65.09	65.33
Green Color Ratio (%)			
Open Sun Drying	-8.49±1.05	1.03±1.27	4.09±1.15

Cabinet Drying	11.55±0.91	44.83±2.41	60.36±2.12
Solar Drying	3.92±1.15	21.42±2.90	16.39±0.32
Ascorbic acid (mg/100g)			
Open Sun Drying	36.47±1.06	38.48±0.68	39.35±1.41
Cabinet Drying	76.37±2.57	58.83±0.94	63.87±1.29
Solar Drying	42.74±0.68	35.53±1.32	37.77±0.39
Total Chlorophyll (mg/100g)			
Open Sun Drying	11.60±0.85	14.27±0.32	19±1.09
Cabinet Drying	17.22±2.12	24.35±0.68	29.13±0.47
Solar Drying	14.78±0.29	18.71±0.64	26.55±0.45
Microbial load (x 10^4 cfu/gm)			
Open Sun Drying	147±3	99±1	88±2
Cabinet Drying	67±2	57±3	49±3
Solar Drying	76±6	55±4	48±4

Uses Harmonic Mean Sample Size = 3.000, Values are mean ±SD, n=3, $P < 0.05$.

3.2.8 Sensory scores

The results of sensory scores of raw and pre-treated dried peas are presented in Table 7. Maximum score of 6.73 in overall acceptability was given to chemically blanched cabinet dried peas followed by water blanched cabinet dried peas (6.31). Minimum score of 5.08 was given to un-blanched open sun dried peas. Overall acceptability of peas dried in solar dryer was between cabinet dried and open sun dried peas. Chemically blanched cabinet dried peas had maximum score of overall acceptability followed by water blanched cabinet dried peas.

Table 7: Results obtained from sensory evaluation of raw and pre-treated dried peas.

Sample	Color	Texture	Aroma	Taste	Overall acceptability
Unblanched Solar Dried	5.6±1.2	5.74±0.88	5.21±1.8	5.53±1.5	5.43±1.01
Water blanched Solar Dried	5.76±1.26	6.17±0.98	5.52±1.51	5.58±1.61	5.76±1.2
Chemically blanched Solar Dried	5.27±1.63	5.75±0.97	5.21±1.77	5.51±1.2	5.43±1.27
Unblanched Cabinet Dried	6.4±0.76	6.5±0.98	5.75±0.86	5.83±1.4	6.12±0.69
Water blanched Cabinet Dried	6.24±1.05	6.11±1.25	6.24±1.57	6.65±0.68	6.31±1.04
Chemical blanched Cabinet Dried	6.77±1.65	6.65±1.41	6.75±1.44	6.74±1.05	6.73±1.21
Unblanched Open Sun Dried	4.76±1.22	5.75±1.71	5.07±1.66	4.72±1.98	5.08±1.34
Water blanched Open Sun Dried	5.22±1.33	5.48±1.59	5.25±1.79	5±1.48	5.24±1.31
Chemically blanched Open Sun Dried	5.46±1.48	5.28±1.6	5.4±1.84	5.12±1.42	5.28±1.4

Values are mean ±SD, n = 9.

3.3. Process dynamics and modeling

3.3.1 Mathematical models for predicting drying behavior of peas

Newton model

The drying constant k of Newton model ($MR=e^{-kt}$) was obtained from the relationship of moisture content and drying time. The semi-logarithmic plot of moisture ratio and drying time represented nearly a straight line. The drying constants determined for all the experiments conducted are shown in Table 8. The average value of k for all the drying experiments was 0.188. The values of R^2 were varied from 0.7912 to 0.9016 and average value was 0.8431. Average value of χ^2 was 0.01372 in all the experiments. RMSE average was 0.006247 and average MBE value was -0.18524. Although, Newton model is simple but the only drawback associated with this model is that it over predicts the early stages and under predicts the later stages of drying (Kashaninejad, Mortazavi, Safekordi, & Tabil, Thin layer drying characteristics and modeling of pistachio nuts, 2007) [12].

Table 8: Drying parameters and statistical parameters of Newton model ($MR = e^{-kt}$).

Drying process	Sample	Drying parameter	Statistical parameter			
		k	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	0.127	0.8059	0.014085	0.004542	-0.07589
	WB	0.164	0.7912	0.0182	0.006554	-0.09207
	CB	0.147	0.8795	0.009607	0.005481	-0.3883
Cabinet Drying	UB	0.173	0.8451	0.012572	0.005584	-0.06902
	WB	0.223	0.9016	0.008949	0.006956	-0.06006
	CB	0.22	0.8435	0.013688	0.006434	-0.7337
Solar Drying	UB	0.193	0.8026	0.017244	0.006307	-0.08658
	WB	0.238	0.8497	0.017537	0.007788	-0.08849
	CB	0.211	0.8692	0.011669	0.00658	-0.07307
Average		0.188	0.8431	0.01372	0.006247	-0.18524

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.2 Henderson and Pabis model

The drying parameters and statistical parameters obtained from Henderson and Pabis model are shown in Table 9. The average value of k for all the drying experiments was 0.237. The value of coefficient of determination R^2 varied from 0.8196 to 0.9113 while average value of χ^2 was 0.029305.

Average RMSE was 0.006545 and average MBE value was 0.019224. The slope of this model (k) is related to the effective diffusivity that controls the process (Kashaninejad, Mortazavi, Safekordi, & Tabil, Thin layer drying characteristics and modeling of pistachio nuts, 2007) [12].

Table 9: Drying and statistical parameters of Henderson and Pabis model ($MR=ae^{-kt}$).

Drying process	Sample	Drying parameter		Statistical parameter			
		k	A	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	0.161	1.3539	0.8517	0.022775	0.000381	0.019522
	WB	0.21	1.5008	0.8196	0.038056	0.001064	0.019266
	CB	0.23	1.5589	0.8042	0.045664	0.001532	0.0257
Cabinet Drying	UB	0.210	1.3337	0.8813	0.019707	0.00027	0.011791
	WB	0.260	1.3337	0.9113	0.015943	0.022443	0.015761
	CB	0.268	1.4419	0.8642	0.02877	0.031213	0.021385
Solar Drying	UB	0.244	1.4276	0.8402	0.032393	0.000702	0.015943
	WB	0.296	1.4993	0.8422	0.037737	0.000953	0.025074
	CB	0.257	1.3785	0.8824	0.022699	0.000345	0.018572
Average		0.237	1.4253	0.8552	0.029305	0.006545	0.019224

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.3 Page model

Drying and statistical parameters obtained from Page model are shown in Table 10. This model is two constant empirical modification of Newton's exponent model. Average value of k for all the drying experiments was 0.074. Coefficient of determination R^2 varied from 0.9410 to 0.9895. Average value of χ^2 was 0.00490 and average RMSE and MBE were 0.00490 and -0.00921, respectively. Average values of statistical parameters indicated a good fit.

Table 10: Drying and statistical parameters of Page model ($MR=e^{-kt}$).

Drying process	Sample	Drying parameter		Statistical parameter			
		k	N	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	0.076	1.351	0.9785	0.00166	0.00402	-0.00629
	WB	0.101	1.347	0.9894	0.00093	0.005260	-0.00606
	CB	0.089	1.386	0.9823	0.00159	0.005445	-0.00989
Cabinet Drying	UB	0.049	1.351	0.941	0.00405	0.003381	-0.00742
	WB	0.060	1.379	0.9550	0.0036	0.00477	-0.01266
	CB	0.069	1.347	0.9532	0.0038	0.00497	-0.01519
Solar Drying	UB	0.067	1.455	0.967	0.00274	0.00466	-0.00932
	WB	0.076	1.516	0.9895	0.00103	0.00631	-0.0088
	CB	0.079	1.448	0.9863	0.00124	0.00532	-0.00727
Average		0.074	1.337	0.9713	0.00490	0.00490	-0.00921

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.4 Overhults model

The results of drying and statistical parameters achieved from Overhults model are shown in Table 11. Average value of k for all the drying experiments was 0.1551. Coefficient of determination R^2 varied from 0.9410 to 0.9894. Average values of χ^2, RMSE and MBE were 0.002403, 0.00489 and -0.00866, respectively. This model also gave a good fit.

Table 11: Drying and statistical parameters of Overhults model ($MR=e^{-kt}$).

Drying process	Sample	Drying parameter		Statistical parameter			
		k	n	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	0.10932	1.354	0.9410	0.0040	0.0033	-0.00747
	WB	0.1297	1.374	0.9550	0.0036	0.00477	-0.00747
	CB	0.1387	1.347	0.9532	0.0038	0.00497	-0.01519
Cabinet Drying	UB	0.1459	1.337	0.9645	0.0027	0.00402	-0.00629
	WB	0.1836	1.347	0.9894	0.00093	0.00526	-0.00619
	CB	0.1745	1.386	0.9823	0.00159	0.00544	-0.00989
Solar Drying	UB	0.1572	1.455	0.9678	0.00274	0.00466	-0.00932
	WB	0.1834	1.516	0.9895	0.00103	0.00631	-0.00889
	CB	0.1736	1.448	0.9863	0.00124	0.00532	-0.00727
Average		0.1551	1.396	0.9698	0.002403	0.00489	-0.00866

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.5 Wang and Singh model

Drying parameters and the statistical parameters obtained from Wang & Singh model are shown in Table 12. Average values of constants a and b for all drying experiments were 0.072 and 0.00109, respectively. Range of coefficient of determination, R^2 was 0.92669-0.9975. Average values of χ^2, RMSE and MBE were 0.001639, 0.008334 and -0.00545, respectively. Due to the lower values of χ^2, RMSE and MBE this model gave better fit as compared to Overhults model.

Table 12: Drying and statistical parameters of Wang and Singh model ($MR=1+at+bt^2$).

Drying process	Sample	Drying parameter		Statistical parameter			
		a	B	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	-0.08	0.00033	0.92669	0.008441	0.009739	-0.07429
	WB	-0.072	0.00024	0.97718	0.00207	0.006079	0.02927
	CB	-0.079	0.00016	0.99681	0.00035	0.009245	0.00126
Cabinet Drying	UB	-0.087	0.000077	0.99384	0.000654	0.007825	-0.00303
	WB	-0.13	0.004	0.99431	0.000613	0.00809	0.005399
	CB	-0.115	0.002	0.99295	0.000878	0.010778	-0.01741
Solar Drying	UB	-0.083	-0.001	0.9975	0.000265	0.007504	0.000217
	WB	-0.115	0.002	0.98920	0.001196	0.008215	0.008596
	CB	0.113	0.002	0.99731	0.000285	0.007535	0.00095
Average		0.072	0.00109	0.985008	0.001639	0.008334	-0.00545

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.6 Logarithmic model

Drying and statistical parameters obtained from logarithmic model are shown in Table 13. It is a single term exponential model and gives two additional parameters "a" and "c" in addition to the drying constant k. The average values of constants k, a, c and χ^2 for all drying experiments were -0.0294, 8.2807, -7.2729 and 0.0002, respectively. Range of coefficient of determination R^2 was 0.98870-0.99846. Average RMSE and MBE were 0.008667 and 1.63 x 10^{-5}, respectively.

Table 13: Drying and statistical parameters of Logarithmic model ($MR=ae^{-kt}+c$).

Drying process	Sample	Drying parameter			Statistical parameter			
		a	k	c	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	16.927	-0.004	-15.901	0.98870	0.001113	0.005999	4.47×10^{-5}
	WB	13.542	-0.006	-12.533	0.99645	0.000411	0.0083	2.876×10^{-5}
	CB	9.935	-0.008	-8.936	0.99679	0.000386	0.00897	1.39×10^{-5}
Cabinet Drying	UB	9.735	-0.009	-8.726	0.99394	0.000716	0.007883	1.57×10^{-5}
	WB	1.586	-0.090	-0.6566	0.99523	0.000618	0.009463	2.72×10^{-8}
	CB	2.205	-0.055	-1.189	0.99630	0.000486	0.009756	1.30×10^{-8}
Solar Drying	UB	14.942	-0.007	-13.916	0.99734	0.000333	0.008355	0
	WB	2.759	-0.046	-1.729	0.99091	0.000697	0.010679	1.91×10^{-8}
	CB	2.896	-0.040	-1.882	0.99846	0.000195	0.008557	4.37×10^{-5}
Average		8.2807	-0.0294	-7.2729	0.99490	0.0002	0.008667	1.63×10^{-5}

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.7 Two term model

Drying and statistical parameters obtained from two term model are shown in Table 14. In this model, a and b are defined as indication of shape and generally named as model constants and *k* and *g* are drying constants. The average values of constants k, g, a and b were 0.176, 0.178, 2.4216 and -1.349, respectively. Range of coefficient of determination, R^2 was 0.91826-0.96489. Average values of χ^2, RMSE and MBE were 0.00709, 0.00643 and 0.00643, respectively.

Table 14: Drying and statistical parameters of two-term model ($MR=ae^{-kt}+be^{-gt}$).

Drying process	Sample	Drying parameter				Statistical parameter			
		a	k	b	g	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	14.374	0.234	-13.42	0.254	0.96253	0.00383	0.00534	0.00215
	WB	0.935	0.134	0.154	0.134	0.91925	0.0086	0.00578	0.00896
	CB	1.026	0.143	0.060	0.143	0.92241	0.0085	0.00623	0.00612
Cabinet Drying	UB	1.001	0.153	0.084	0.153	0.92969	0.00797	0.00571	0.00799
	WB	0.821	0.195	0.259	0.195	0.96489	0.00455	0.00749	0.00907
	CB	0.927	0.184	0.157	0.184	0.94934	0.00648	0.00728	0.01009
Solar Drying	UB	0.987	0.163	0.106	0.163	0.91826	0.00980	0.00582	0.00844
	WB	0.891	0.196	0.21	0.196	0.93928	0.0083	0.00774	0.0108
	CB	0.833	0.182	0.249	0.182	0.95418	0.00583	0.00656	0.0037
Average		2.4216	0.176	-1.349	0.178	0.939981	0.00709	0.00643	0.00748

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.8 Two term exponential model

Drying and statistical parameters obtained from two term exponential model are shown in Table 15. The average values of constants k and a for all the drying experiments were 0.13411 and 0.94677, respectively. Range of coefficient of determination, R^2 was 0.8534-0.9987. Average values of χ^2, RMSE and MBE were 0.004442, 0.006189 and -0.00022, respectively.

Table 15: Drying and statistical parameters of two-term exponential model ($MR=ae^{(-kt)} + (1-a)e^{-kat}$).

Drying process	Sample	Drying parameter		Statistical parameter			
		a	k	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	0.99	0.1	0.8534	0.008621	0.002541	-0.00834
	WB	0.989	0.121	0.8742	0.00872	0.003535	-0.00634
	CB	1.989	0.209	0.9692	0.00315	0.007759	0.010503
Cabinet Drying	UB	-0.878	-0.035	0.9936	0.00066	0.007644	0.000558
	WB	1.931	0.277	0.9917	0.000935	0.008915	0.005826
	CB	0.996	0.168	0.9204	0.006559	0.004724	-0.0026
Solar Drying	UB	-0.456	-0.077	0.9987	0.00136	0.008182	-0.00126
	WB	0.990	0.177	0.8962	0.00860	0.004606	-0.00554
	CB	1.970	0.267	0.9872	0.00137	0.007796	0.005233
Average		0.94677	0.13411	0.942733	0.004442	0.006189	-0.00022

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.9 Verma model

The drying and statistical parameters obtained from **V**erma model are shown in Table 16. The average values of constants k, a and g for all the drying experiments were 0.23911, -26.1919 and 0.24644, respectively. Range of coefficient of determination R^2 was 0.96240-0.9959. Average value of χ^2, RMSE and MBE were 0.001963, 0.008025 and 0.00437, respectively.

Table 16: Drying and statistical parameters of Verma model ($MR = ae^{-kt} + (1-a)e^{-gt}$).

Drying process	Sample	Drying parameter			Statistical parameter			
		a	k	g	R^2	χ^2	RMSE	MBE
Open Sun Drying	UB	14.422	0.224	0.241	0.96240	0.003586	0.005618	0.007185
	WB	16.635	0.261	0.277	0.97130	0.003178	0.00757	0.00249
	CB	-11.385	0.293	0.270	0.97322	0.003067	0.008101	0.010113
Cabinet Drying	UB	-16.625	0.316	0.298	0.98197	0.00154	0.007301	0.008226
	WB	9.49	0.346	0.381	0.99326	0.000858	0.00913	0.005253
	CB	-231.44	0.025	0.026	0.9959	0.000526	0.009255	-0.0024
Solar Drying	UB	-20.250	0.346	0.329	0.97759	0.002674	0.007533	0.008033
	WB	-5.697	0.006	0.023	0.9934	0.000884	0.00974	-0.00426
	CB	9.123	0.335	0.373	0.98901	0.00135	0.00798	0.00469
Average		-26.1919	0.23911	0.24644	0.98200	0.001963	0.008025	0.00437

UB, WB and CB are un-blanched, water blanched and chemically blanched sample, respectively.

3.3.10 Selection of best fitted model

Average values of all the parameters of all the models applied for curve fitting are listed in Table 17. Nine mathematical drying models were applied and drying curves were tested to select the best model based on the quality of fit for describing drying behavior. The coefficient of determination (R^2) along with the reduced chi-square (χ^2), root mean square error (RMSE) and mean bias error (MBE) were considered to select best model. Higher value of correlation coefficient along with lower value of RMSE indicated better fitting of the drying curve. Lower value of reduced chi-square along with lower value of MBE indicated the goodness and adequacy of the curve fitting. Value of R^2 for Newton model was 0.8431 which was lowest among all the models applied. Value of χ^2 for Newton model was 0.01372 which was less than only Henderson and Pabis model. RMSE and MBE values for Newton model were 0.00624 and -0.1852, respectively. While, Newton model did not give fine estimate of drying parameters. Value of R^2 for Henderson and Pabis model was 0.8552 which was second lowest among all nine models. Value of χ^2 for Henderson and Pabis model was 0.29305 which was highest among all models. RMSE and MBE values for Henderson and Pabis model were 0.00654 and -0.1852, respectively. Because of low value of R^2 and high value of chi square, Henderson and Pabis did not give high-quality estimate for drying parameters. Page, Overhults and Wang and Singh models had higher values of R^2 as compared to formerly discussed models. Verma model, Two term exponential model and Two term model also illustrated good fit to the drying kinetics of peas. Among all, Logarithmic model with highest value of R^2 (0.9949), lowest value of χ^2 (0.00020), low value of RMSE (0.00866) and low value of MBE (1.63 x 10^{-5}) made it the most suitable model to represent drying in peas. It gave the best estimate of drying parameters which fitted well with the experimental drying curves and gave a good set of statistical parameters for green peas. Emy *et al.* also reported that Logarithmic model was the best model among Fick, Page and Logarithmic for explaining drying kinetics of mushrooms. They dried fresh and osmosed mushrooms in a vertical bed dryer with forced airflow at different temperatures and air velocities (Emy, Moreira, & Elizabeth, 2012) [4].

Table 17: Comparative data regarding curve fitting criteria of various drying models.

Model	Statistical Parameter			
	R^2	χ^2	RMSE	MBE
Newton	0.8431	0.01372	0.00624	-0.1852
Henderson & Pabis	0.8552	0.29305	0.00654	0.0192
Page	0.9713	0.00229	0.00490	-0.0092
Overhults	0.9698	0.00240	0.00489	-0.0086
Wang & Singh	0.9850	0.00163	0.00833	-0.0054
Logarithmic	0.9949	0.00020	0.00866	1.63 x 10^{-5}
Two term	0.9399	0.00709	0.00643	0.00748
Two term exponential	0.9427	0.00444	0.00061	-0.0002
Verma	0.9820	0.00196	0.00802	0.0043

4. Conclusion

Drying rate was maximum in water blanched sample followed by chemically blanched sample which were dried in solar dehydrator. Time required to dry green pea under open sun, in cabinet dryer and in solar dehydrator was 13h, 11h and 10h, respectively. Drying occurred in falling rate drying period. Highest RR, GCR and chlorophyll were observed in chemically blanched cabinet dried peas and lowest in un-blanched open sun dried peas indicating that there was positive effect of chemical blanching on color retention and addition of chemicals during blanching positively affected chlorophyll retention. Highest LSR was observed in water blanched peas dried in cabinet dryer and least in peas which was chemically blanched and dried under open sun. Maximum ascorbic acid content was in un-blanched peas dried in cabinet dryer and minimum in water blanched peas dried in solar dehydrator. Maximum microbial load was observed in open sun dried un-blanched sample because of exposure to outer environment and dirt and minimum microbial load was observed in chemically blanched solar dried sample due to isolation from outer environment and destruction of microbes during blanching. Chemically blanched peas dried in cabinet dryer were considered best among all the treated peas dried under different drying conditions and least acceptance was given to un-blanched open sun dried peas. Quality and acceptability of solar dried peas were higher than open sun drying but lower than cabinet drying. While considering models, Logarithmic model gave a very good performance on all the statistical parameters. So, it can be used to predict the drying behavior of green peas.

5. Declaration

Work described has not been published before, it is not under consideration for publication elsewhere, its submission to JFST publication has been approved by all authors as well as the responsible authorities, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright holder.

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