Effect of drying temperatures and pre-treatments on drying characteristics, energy consumption, and quality of bell pepper

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Abstract: The effect of air temperature (50°C, 60°C, 70°C, 80°C and 90°C) and pre-treatments (steam, water palm oil-water, groundnut oil-water blanching) on the drying characteristics and quality of bell pepper was investigated. The results were fitted to six thin-layer drying models and Parabolic model gave the best fit. The pretreated samples dried faster than untreated samples and had lower values of total energy needed and specific energy requirement. The ascorbic acid content, color and rehydration index varied from 129.1 to 316.8 mg/100 g dry matter, 0.1 to 0.9, 22 to 33 mL and pretreated dried pepper generally had higher values than untreated samples.

Keywords: modeling, energy consumption, Rehydration index, color, pepper

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1 Introduction

Bell pepper is commonly used as a food or dried as a condiment. The high moisture content of the fresh pepper makes it highly perishable and susceptible to deterioration. Drying is one of the common preservative methods for bell pepper. Drying lowers water activity which increases shelf-life of the product, reduces the storage volume and decreases transport costs (Ade-Omowaye et al., 2003; Vega et al., 2007). The dried product has a number of applications. Sun drying is a slow process that is weather dependent and is thus difficult to control. This exposes the product to environmental hazard and results in products of low quality. Long dehydration times lead to poor quality products due to factors which include caramelisation, Maillard reactions, enzymatic reactions, pigment degradation and L-ascorbic acid oxidation (Homer, 1993). During large scale food production especially that of bell pepper in the northern part of Nigeria, large percentage of postharvest losses is experienced in the production process. As a result of this, the traditional sun-drying method needs to be replaced with efficient drying systems to reduce these losses. Hot air drying has been identified by a number of authors as a more efficient drying method. This is due to the fact that heat and mass transfer can be controlled during the drying process to achieve desired product quality.

Hot air drying however results in depletion of some food nutrients as well as undesirable color and textural changes (Adedeji et al., 2008). Minimizing the reduction in the nutritional quality of the dried food products can be achieved by the use of various pretreatment methods prior to drying. Another use of pretreatments before drying is to remove the wax barrier on fruits or vegetables and thus to reduce drying time. This thin layer of wax which offers benefits such as protection to the fruit or vegetable from environmental and external factors retards the flow of moisture to the fruit surface a crucial factor in drying process (Doymaz, 2007). Pretreatments methods which include blanching,

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chemical pretreatment and osmotic dehydration improve nutritional quality of the dried products as well as reduce the dehydration time of the drying process (Akanbi et al., 2003; Kingsly et al., 2007). The use of chemical additives in foods is being discouraged due to its health implications. Increased demand for natural foods with less or no chemical additives in them has resulted in the need for pretreatment methods other than chemical pretreatment methods.

Blanching is a pretreatment carried out primarily to inactivate natural enzymes (Canoet al., 1990) and loosens tissues which results in a faster drying process. Blanching is usually done by water and steam blanching but in some cases oil/water blanching has been carried out (Akanbi et al., 2003). The use of blanching to increase the drying rate of fruits have been have reported (Turhan et al., 1997). Oil water blanching was observed to increase the drying rate and the resultant dried samples had higher vitamin C content and colour when compared with untreated samples.

The physicochemical and quality characteristics of a product are influenced by drying therefore the evaluation of the drying characteristics has to be crop specific. The determination of the drying characteristics as a function of drying conditions could help in predicting suitable drying conditions (Hamdami et al., 2006). The moisture removal of a crop and its dependence on the process variables is indicated by its drying kinetics which is essential for the development of reliable process models (Guine and Fernandes, 2006). Work done on the drying kinetics of various pretreated fruits and vegetables including tomatoes (Doymaz, 2007), red pepper (Akpinar et al., 2003), bell pepper (Tunde-Akintunde et al., 2005), sweet pepper (Vengaiah and Pandey, 2007) and okra (Sobukola, 2009) have been reported. The drying characteristic of each food material is unique and thus will behave uniquely during drying. Studies on the thin layer drying of food materials have to be carried out for individual food material since this is the basis of understanding the drying characteristics. Work have been conducted on modeling of the kinetics of thin layer drying of some food materials, sweet pepper (Vengaiah and Pandey, 2007), okra (Sobukola, 2009), garlic cloves (Sharma and Prasad, 2004), tomatoes (Sogi et al., 2003) and cocoa (Hii et al., 2009) using empirical, semi-theoretical or theoretical models.

Though there has been some work done on the drying of bell pepper and the effect of steam and water blanching on the drying rate of fruits and vegetables, there has not been much done on other types of blanching methods especially oil blanching. This lack of published work on the air-drying kinetics of crops pretreated with oil/water blanching, either in terms of empirical models or in terms of diffusivity model explains the interest for the present work. This study investigates the effect of various blanching methods on the drying characteristics and quality of bell pepper and to fit the experimental data obtained to some of the generally accepted thin layer drying models.

2 Materials and methods

2.1 Drying procedure

Freshly harvested red bell pepper (*Capiscum annum*) samples with nearly the same dimension (width, length and breadth) and in very good conditions was purchased from a local market in Ogbomoso town in Western Nigeria. The samples were washed; drained and other extraneous materials were removed completely. The blanching pre-treatments used for inactivation of enzymes of bell pepper are as indicated in Table 1 while untreated samples (UT) were used as the control.

A hot-air dryer (Gallenkamp, UK) with three tiers of trays was used to dry the bell pepper samples. Perforated trays with an area of approximately 0.2 m^2 were filled with a single layer of bell pepper. The air circulated parallel to the samples at the food surface and bottom of the perforated trays, at 2.0 m/s. The inlet average temperature was constant in each experiment, and experiments were conducted at different temperatures of 40°C, 60°C and 80°C and drying was stopped when constant weight was reached with three consecutive readings. For each experimental run, the dryer was allowed to run for 2 hours, about half an hour before the start of experiment to stabilize it at the specified air conditions before the drying of the samples began. Weight loss of samples was periodically measured (from

30 min at the beginning of the drying to 120 min during the last stages of the drying process) by means of a digital balance (PH Mettler) with an accuracy of ±0.01 g. The experiments were repeated twice and the average of the moisture ratio at each value was used for drawing the drying curves.

Table 1 Pretreatment methods for bell pepper

Treatment	Description
WB	Submerged samples in boiling water for 3 min and cooling immediately in tap water
SB	Steamed over boiling water in a water bath (WBH 14/F2, England) for 3 min and cooled immediately in tap water
PB	Dipped for 3 min in a homogenized mixture of palm oil and water of ratio 1:20 (v/v) with 0.1 g of butylated hydroxyl anisole (BHA) heated to 95°C
GB	Dipped for 3 min in a homogenized mixture of groundnut oil and water of ratio 1:20 (v/v) with 0.1 g of butylated hydroxyl anisole (BHA) heated to 95°C

2.2 Theoretical considerations

Based on the initial moisture content from oven drying, the moisture content was determined from the weight loss using the equation below (Kajuna et al, 2001).

$$M_{tw} = \frac{M_{iw} m_i - w_i}{m_i - w_i} \tag{1}$$

where, M_{tw} is the moisture content at time t, (kg water/kg wet material); M_{iw} the initial moisture content, (kg water/kg wet material); m_i is the initial weight, g; and w_i is the weight loss at time t, g. The moisture content M_{tw} and M_{iw} was converted to M_t and M_i using the following equation:

$$M = \frac{M_w}{1 - M_w} \tag{2}$$

where, M, represents either M_t or M_i and M_w represents either M_{tw} or M_{iw}; M_t is moisture content at any time of drying in % dry basis (kg water/kg dry matter); M_i is initial moisture content in % dry basis (kg water/kg dry matter).

The moisture content, M_t was converted to moisture ratio (M_R) using thin-layer equations being considered.

The moisture ratio was calculated as follows:

$$M_R = \frac{M_t - M_e}{M_i - M_e} = \exp(-kt) \tag{3}$$

where, M_t is moisture content at any time of drying (kg water/kg dry matter); M_i is initial moisture content, kg water/kg dry matter; and M_e is equilibrium moisture content, kg water/kg dry matter, respectively.

The drying rate for bell pepper was calculated as follows:

$$D_R = \frac{M_{t+dt} - M_t}{dt} \tag{4}$$

where, M_{t+dt} is moisture content at $t + dt$, kg water/kg dry matter and t is time, min.

In order to describe the drying characteristics of pretreated and untreated bell pepper, the drying curves (M_R versus time) obtained were fitted with six semi-theoretical thin layer drying models namely - Exponential model, Generalized exponential model, Logarithmic model, Page's model, Middili–Kucuk model and Parabolic model. The models are shown in Table 2.

Table 2 Mathematical models fitted to pretreated and untreated bell pepper drying curves

Model name	Model	References
Exponential model	$MR=\exp(-kt)$	Tiris et al. (1994) and El-Beltagy et al. (2007)
Generalized exponential model	$MR=A\exp(-kt)$	Henderson and Pabis (1961) and Shittu and Raji (2010)
Logarithmic model	$MR=a\exp(-kt)+c$	Wang et al. (2007), and Akpinar and Bicer (2008)
Page's model	$MR=\exp(-kt^n)$	Madamba (2003) and Singh et al. (2008)
Midilli–Kucuk model	$MR=a\exp(-kt^n)+bt$	Midilli et al. (2002)
Parabolic model	$MR=a+bt+ct^2$	Sharma and Prasad (2004), Doymaz,(2010)

A nonlinear regression procedure for the six models was done using Statistical Package for social scientists (SPSS) 11.5.1 software package. The criteria used for selecting the best model to define the drying curves are the coefficient of determination (R^2), the reduced chi-square (χ^2), root mean square error (RMSE) and mean bias error (MBE). These criteria were used to determine the quality of the fit of the models. The drying model with value of R^2 and the lower the values of χ^2, RMSE and MBE was chosen as the best model describing the thin layer drying characteristics of bell pepper. This is because the higher the values of R^2, and the lower the values of RMSE, the better the goodness of fit (Hii et al., 2009; Doymaz, 2010; Vega-Galvez et al., 2008).

These parameters can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}(M_{R(\exp,t)} - M_{R(pred,t)})^2}{N-z} \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}(M_{R(pred,t)} - M_{R(\exp,t)})^2\right]^{\frac{1}{2}} \quad (6)$$

$$MBE = \left[\frac{1}{N}\sum_{i=1}^{N}(M_{R(pred,i)} - M_{R(\exp,i)})\right] \quad (7)$$

In the above equations $MR_{\exp,i}$ and $MR_{pred,i}$ are experimental and predicted dimensionless moisture ratios, respectively; N is number of observations; z is number of constants.

2.3 Determination of energy consumption

The total needed energy for drying one charge of the heater and energy requirements for drying 1 kg of fresh bell pepper slices were calculated for each experiment using the following equation:

$$E_t = A\upsilon\rho_a c_a \Delta T D_t \quad (8)$$

where, E_t is total needed energy for drying at each condition of the experiments; A is tray area; v is air velocity; ρ_a is air density; D_t is total drying time, min; ΔT is temperature differences and c_a is the specific heat of air.

$$E_{kg} = \frac{E_t}{W_o} \quad (9)$$

where, E_{kg} is specific energy requirement, kWh/kg; and W_o is initial weight, g.

2.4 Determination of quality parameters

The rehydration index was determined using the method of Farkas, et al. (1982). Five grams of dried pepper sample was mixed in boiling water and shaken for 60 seconds. The mixture was then poured into a 100 mL graduated glass cylinder and allowed to settle for 10 min. After 10 min, the volume of the sediment was recorded as the rehydration index. The colour of the samples was determined by soaking 5 g of each sample in 20mL of distilled water for 12 h. After soaking the mixtures were filtered and the transmittance at 470 nm of the filtrate was determined using a colorimeter (CIBA, Corning 252, England). The Pungency was determined according to American Spice Trade Association (ASTA, 1985) method. The 1g of ground pepper with 100 mL 95% ethyl alcohol was extracted for 16 h. An aliquot of the extracted (1 mL) was diluted to 50 mL with sucrose solution in a volumetric flask. A small quantity (5 mL) of the solution was swallowed by each of the 5 reliable tasters. The judgment as to whether or not heat or sweetness is present was made between 20 – 30 seconds after swallowing using scales. Vitamin C (AA) was determined based upon the quantitative discolouration of 2,6-dichlorophenol indophenol (Merck KgaA, Darmstadt, Germany) titrimetric method as described in AOAC methodology No. 967.21 (AOAC, 200). The vitamin C content was expressed as mg AA retained/100 g dry matter. All measurements were done in triplicate.

3 Results and discussions

3.1 Drying curves

The drying curve (moisture ratio versus time) for the drying of pretreated and untreated bell pepper at the temperatures studied (50°C, 60°C, 70°C, 80°C and 90°C) are shown in Figures 1–5. The moisture ratio is observed to decrease with increase in drying time. At the initial stages of the drying process, the removal of moisture was highest and this decreased with increase in drying time until equilibrium was reached at which moisture removal reduced to zero. This is in agreement with the observations of various authors (Doymaz, 2010; Sacilik et al., 2006, Mota et al., 2010). The increase in drying temperature was also observed to accelerate the drying process, thus the drying time reduced with an increase in drying temperature. The time taken for the drying process to reach equilibrium at the various drying temperatures varied from 420 to 660 min. At 50°C the drying reached equilibrium after approximately 660 min, however this reduced to 420 min at 90°C, representing a reduction in the drying time of approximately 40%. This is probably due to the fact that at higher drying temperatures there is a greater difference in the partial vapor pressure between the plantain slices and their surroundings which result in higher moisture migration from internal regions and evaporation at the product surface. Drying generally took place during the falling rate period. During this period drying was mainly controlled by diffusion mechanisms. This is similar to the results obtained for various fruits and vegetables (Doymaz, 2007; Sogi et al., 2003; Doymaz, 2010; Sacilik et al., 2006).

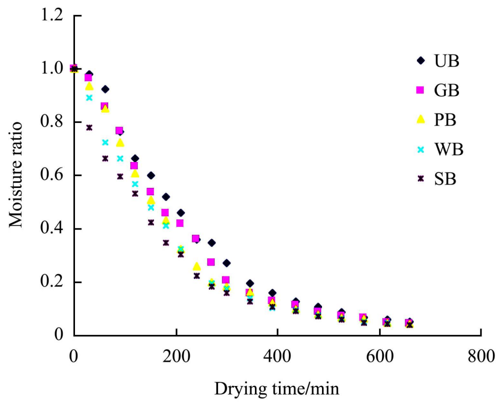

Figure 1 Drying curve for pretreated bell pepper dried at 50°C

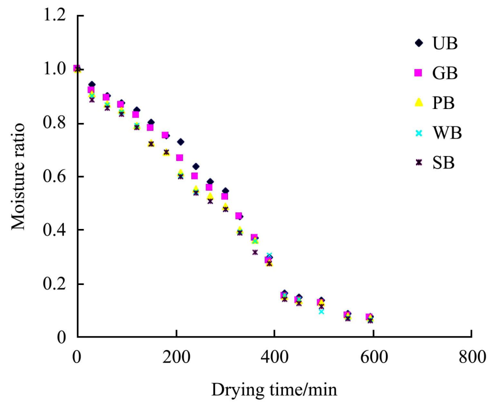

Figure 2 Drying curve for pretreated bell pepper dried at 60°C

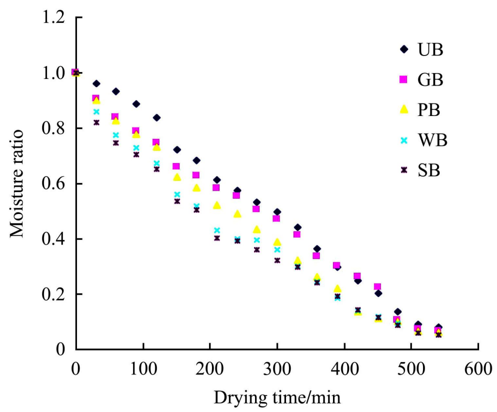

Figure 3 Drying curve for pretreated bell pepper dried at 70°C

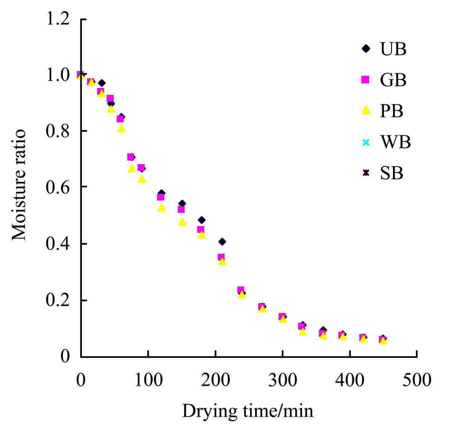

Figure 4 Drying curve for pretreated bell pepper dried at 80°C

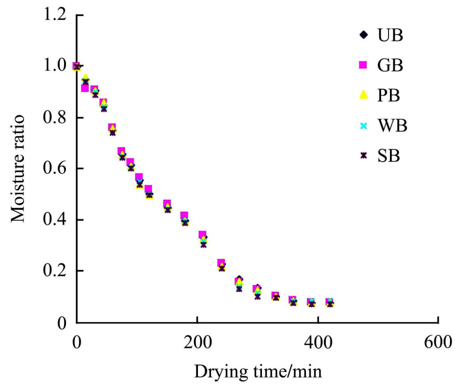

Figure 5 Drying curve for pretreated bell pepper dried at 90°C

The effects of the blanching pre-treatment on the moisture ratio of the bell pepper over drying time are shown in Figures 1–5. From these figures, generally the blanching pre- treatment gave lower drying curves than the untreated bell pepper. This indicates that the blanching pretreatments are a significant factor for the bell pepper drying because it affects the drying time. The drying process took about 650, 600, 590, 580 and 540 min to reach a moisture ratio of about 0.52 at 50°C for UB, GB, PB, WB, SB samples respectively. Thus the various blanching pretreatments can decrease the drying time by about 7.5%, 9.2%, 10.8%, and 16.9% respectively. This increase in drying time due to pretreatment is reported for other fruits and vegetables including peach slices, apple and chili (Kingsly et al., 2007, Hossain and Bala, 2007, Doymaz, 2010).

Table 3 Curve fitting data of the six drying models for drying kinetics of steam blanched Bell pepper

Air temperature /°C	Model name	Coefficient of determination (R^2)	Reduced chi-square (χ^2)	Root mean square error (RMSE)
50	Exponential	0.9907	0.000915	0.029437
	Generalized exponential	0.9913	0.00095	0.029148
	Logarithmic	0.9930	0.00076	0.025302
	Page	0.9912	0.000676	0.024595
	Midilli–Kucuk	0.9912	0.000719	0.023817
	Parabolic	0.9930	0.000546	0.021449
60	Exponential	0.8880	0.011415	0.103990
	Generalized exponential	0.9092	0.009545	0.092412
	Logarithmic	0.9733	0.00306	0.050760
	Page	0.9701	0.003091	0.051021
	Midilli–Kucuk	0.9695	0.003159	0.049940
	Parabolic	0.9752	0.002223	0.044595

Air temperature /°C	Model name	Coefficient of determination (R^2)	Reduced chi-square (χ^2)	Root mean square error (RMSE)
70	Exponential	0.9457	0.004281	0.063683
	Generalized exponential	0.9498	0.004403	0.062765
	Logarithmic	0.9935	0.000626	0.022964
	Page	0.9637	0.002547	0.047741
	Midilli–Kucuk	0.9943	0.000467	0.019199
	Parabolic	0.9943	0.000398	0.018297
80	Exponential	0.9580	0.005216	0.070294
	Generalized exponential	0.9735	0.003433	0.055418
	Logarithmic	0.9840	0.002301	0.044015
	Page	0.9867	0.00148	0.036391
	Midilli–Kucuk	0.9875	0.369124	0.539827
	Parabolic	0.9882	0.001392	0.034236
90	Exponential	0.9822	0.001805	0.041349
	Generalized exponential	0.9886	0.001262	0.033609
	Logarithmic	0.9928	0.000842	0.026635
	Page	0.9937	0.000591	0.023001
	Midilli–Kucuk	0.9927	0.000667	0.022941
	Parabolic	0.9947	0.000581	0.022129

Table 4 Curve fitting data of the six drying models for drying kinetics of water blanched Bell pepper

Air temperature /°C	Model name	Coefficient of determination (R^2)	Reduced chi-square (χ^2)	Root mean square error (RMSE)
50	Exponential	0.9823	0.001751	0.040731
	Generalized exponential	0.9895	0.001076	0.031033
	Logarithmic	0.9934	0.000777	0.025583
	Page	0.9980	0.000179	0.012652
	Midilli–Kucuk	0.9975	0.0002256	0.013792
	Parabolic	0.9988	0.000156	0.011091
60	Exponential	0.9199	0.007704	0.085434
	Generalized exponential	0.9302	0.007116	0.079795
	Logarithmic	0.9807	0.001991	0.040943
	Page	0.9785	0.002406	0.046397
	Midilli–Kucuk	0.9777	0.002026	0.039990
	Parabolic	0.9794	0.001991	0.040943
70	Exponential	0.9825	0.001342	0.035658
	Generalized exponential	0.9827	0.001427	0.035732
	Logarithmic	0.9934	0.000632	0.023065
	Page	0.9779	0.001411	0.035529
	Midilli–Kucuk	0.9946	0.000352	0.01666
	Parabolic	0.9957	0.000299	0.015863
80	Exponential	0.9727	0.003345	0.056294
	Generalized exponential	0.9836	0.002189	0.044256
	Logarithmic	0.9897	0.001485	0.035357
	Page	0.9912	0.001003	0.02996
	Midilli–Kucuk	0.9906	0.001137	0.02996
	Parabolic	0.9927	0.000883	0.027274
90	Exponential	0.9831	0.001763	0.04087
	Generalized exponential	0.9870	0.001413	0.035558
	Logarithmic	0.9922	0.000837	0.026554
	Page	0.9919	0.000752	0.025933
	Midilli–Kucuk	0.9912	0.000839	0.025736
	Parabolic	0.9931	0.000687	0.024044

Table 5 Curve fitting data of the six drying models for drying kinetics of Palm oil/Water blanched Bell pepper

Air temperature /°C	Model name	Coefficient of determination (R^2)	Reduced chi-square (χ^2)	Root mean square error (RMSE)
50	Exponential	0.9942	0.000486	0.021456
	Generalized exponential	0.9957	0.000337	0.017375
	Logarithmic	0.989	0.000397	0.018283
	Page	0.9941	0.000646	0.023329
	Midilli–Kucuk	0.9941	0.000388	0.017512
	Parabolic	0.9962	0.000319	0.016897
60	Exponential	0.9264	0.006897	0.080835
	Generalized exponential	0.9384	0.006114	0.073965
	Logarithmic	0.9828	0.001668	0.037481
	Page	0.9782	0.001914	0.041378
	Midilli–Kucuk	0.9844	0.001636	0.037122
	Parabolic	0.9849	0.001581	0.035331
70	Exponential	0.9784	0.001873	0.042122
	Generalized exponential	0.9789	0.001825	0.040407
	Logarithmic	0.9910	0.000693	0.024161
	Page	0.9783	0.00138	0.035141
	Midilli–Kucuk	0.9912	0.000731	0.024027
	Parabolic	0.9921	0.000669	0.023732
80	Exponential	0.9710	0.003742	0.059541
	Generalized exponential	0.9824	0.002229	0.044657
	Logarithmic	0.9866	0.001819	0.039139
	Page	0.9888	0.001277	0.033796
	Midilli–Kucuk	0.9898	0.001484	0.03423
	Parabolic	0.9903	0.001197	0.031754
90	Exponential	0.9844	0.001656	0.039608
	Generalized exponential	0.9903	0.001116	0.031602
	Logarithmic	0.9927	0.000798	0.025921
	Page	0.9928	0.000681	0.024283
	Midilli–Kucuk	0.9929	0.000738	0.024132
	Parabolic	0.9930	0.000659	0.023955

Table 6 Curve fitting data of the six drying models for drying kinetics of Groundnut oil/Water blanched Bell pepper

Air temperature /°C	Model name	Coefficient of determination (R^2)	Reduced chi-square (χ^2)	Root mean square error (RMSE)
50	Exponential	0.9655	0.004059	0.062012
	Generalized exponential	0.9787	0.002466	0.046972
	Logarithmic	0.9788	0.002617	0.002612
	Page	0.9785	0.002028	0.042594
	Midilli–Kucuk	0.969	0.00301	0.030899
	Parabolic	0.9886	0.001209	0.002427
60	Exponential	0.9348	0.006005	0.075426
	Generalized exponential	0.9467	0.00516	0.06795
	Logarithmic	0.9862	0.001471	0.035192
	Page	0.9858	0.00153	0.036997
	Midilli–Kucuk	0.9845	0.001355	0.033775
	Parabolic	0.9862	0.001309	0.032148

Air temperature /°C	Model name	Coefficient of determination (R^2)	Reduced chi-square (χ^2)	Root mean square error (RMSE)
70	Exponential	0.9593	0.003622	0.058578
	Generalized exponential	0.9652	0.003339	0.054658
	Logarithmic	0.9951	0.000423	0.018866
	Page	0.983	0.001357	0.034839
	Midilli–Kucuk	0.9943	0.00052	0.020258
	Parabolic	0.9956	0.000404	0.018445
80	Exponential	0.9848	0.001708	0.040228
	Generalized exponential	0.9893	0.001321	0.034378
	Logarithmic	0.9917	0.001117	0.030667
	Page	0.9925	0.001037	0.029549
	Midilli–Kucuk	0.9914	0.000839	0.025734
	Parabolic	0.9925	0.000758	0.026045
90	Exponential	0.9843	0.001666	0.03973
	Generalized exponential	0.9894	0.001226	0.033124
	Logarithmic	0.9920	0.001034	0.029503
	Page	0.9923	0.000765	0.026167
	Midilli–Kucuk	0.9924	0.000838	0.025726
	Parabolic	0.9935	0.000628	0.022989

Table 7 Curve fitting data of the six drying models for drying kinetics of Untreated Bell pepper

Air temperature /°C	Model name	Coefficient of determination (R^2)	Reduced chi-square (χ^2)	Root mean square error (RMSE)
50	Exponential	0.9664	0.003816	0.060123
	Generalized exponential	0.9792	0.002457	0.046884
	Logarithmic	0.9798	0.046944	0.046901
	Page	0.9876	0.001163	0.032254
	Midilli–Kucuk	0.9773	0.050345	0.045206
	Parabolic	0.9961	0.000399	0.017758
60	Exponential	0.8776	0.012837	0.110278
	Generalized exponential	0.9047	0.010816	0.098374
	Logarithmic	0.9693	0.003375	0.053314
	Page	0.9699	0.003098	0.051075
	Midilli–Kucuk	0.9685	0.0036	0.05331
	Parabolic	0.9715	0.001656	0.038495
70	Exponential	0.9206	0.007266	0.082966
	Generalized exponential	0.9451	0.005556	0.070507
	Logarithmic	0.9956	0.000505	0.020624
	Page	0.9956	0.000906	0.028474
	Midilli–Kucuk	0.9953	0.000469	0.019249
	Parabolic	0.9957	0.000382	0.017935
80	Exponential	0.9655	0.004387	0.064471
	Generalized exponential	0.9789	0.002828	0.050304
	Logarithmic	0.9886	0.001502	0.035569
	Page	0.9927	0.000817	0.026803
	Midilli–Kucuk	0.9924	0.00091	0.026803
	Parabolic	0.9934	0.000803	0.026235
90	Exponential	0.9884	0.00117	0.033296
	Generalized exponential	0.9916	0.000914	0.02859
	Logarithmic	0.9928	0.000601	0.022499
	Page	0.9932	0.00071	0.024457
	Midilli–Kucuk	0.9934	0.000714	0.023745
	Parabolic	0.9942	0.000585	0.022872

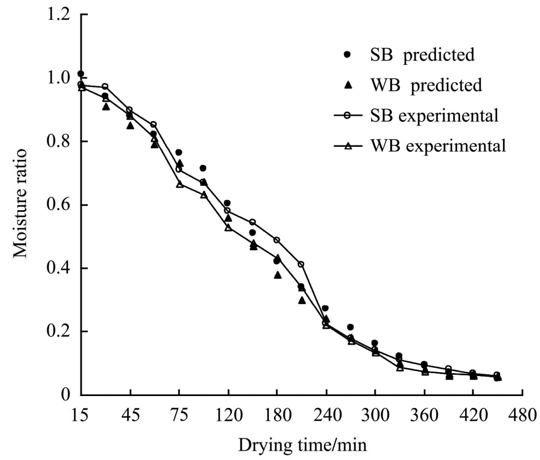

Figure 6 Comparison between experimental and predicted moisture ratios for pretreated bell pepper dried at 80°C using the Parabolic model

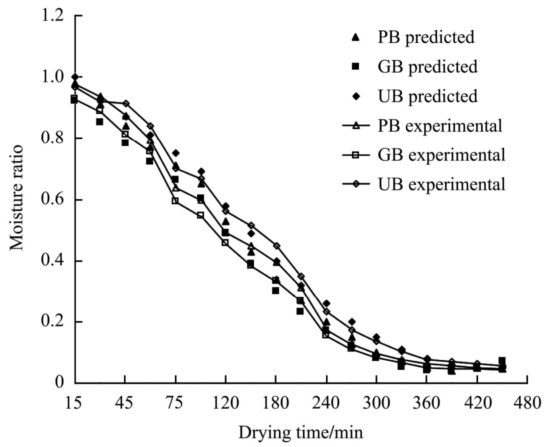

Figure 7 Comparison between experimental and predicted moisture ratios for pretreated (oil/water blanching) and untreated bell pepper dried at 80°C using the Parabolic model

3.3 Energy consumption

Optimization of the energy process involves the use of minimal energy to achieve maximum moisture removal therefore determination of the energy consumption is of great importance. The total energy needed for drying at each condition of dryer condition and the energy requirements for drying 1kg of bell pepper was determined for each experiment using Equation (8) and Equation (9), respectively, (Figure 8 and Figure 9). The total needed energy which varied from 24.17 kWh to 42.91 kWh was obtained with steam blanched pretreated pepper at a drying air temperature of 80°C and with untreated pepper at a drying air temperature of 60°C. The maximum and minimum value of specific energy requirement of 214.53 kWh/kg and 120.87 kWh/kg was obtained for untreated pepper dried at drying air temperature of 60°C and steam blanched bell pepper dried at 80°C respectively. The values obtained for the total needed energy and the specific energy requirements for the pretreatment processes and higher drying temperature were generally lower than those obtained both for the untreated samples and for lower drying temperatures. This shows that the use of pretreatment lowers the total energy needed and specific energy requirement for the drying of bell pepper thus reducing energy utilization during drying which is desirable. This also confirms the initial observation that pretreatment aids drying of bell pepper thus the use of pretreatments during the drying of bell pepper can be used for optimization of energy utilization especially in areas where cost of energy usage is high.

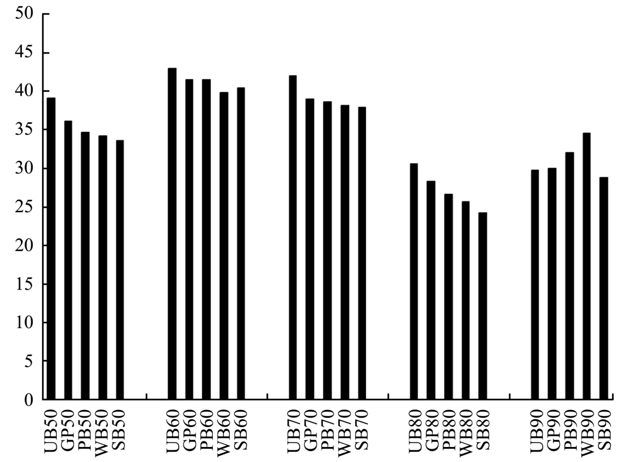

Figure 8 Total needed energy (kWh) for drying of bell pepper at different air drying temperatures and levels of pretreatment

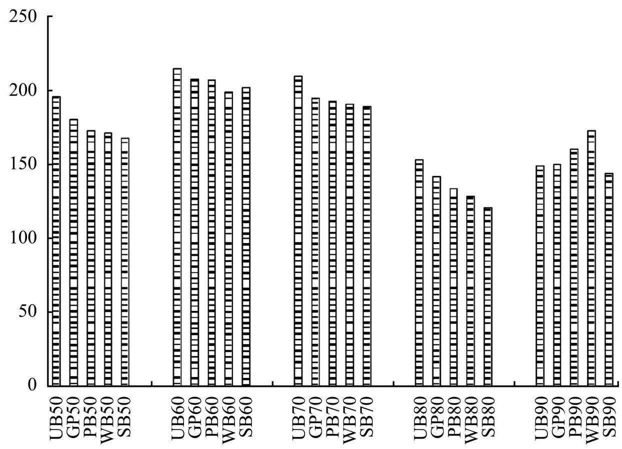

Figure 9 Specific energy requirement (kWh/kg) for drying of bell pepper at different air drying temperatures and levels of pretreatment

3.4 Effect of drying temperature and pretreatment on quality of dried pepper

The vitamin C content (which was determined as AA-Ascorbic Acid content) was observed to decrease with increase in drying temperature while the pretreated samples had higher vitamin content than the untreated samples (Table 8). This may be due to the irreversible oxidative processes during drying and the heat sensitive nature of vitamin C (Vega-Galvez et al., 2009). The heat sensitive nature of vitamin C due to its low stability during thermal processes is considered as an indicator of the quality of food processing (Podsedek, 2007). This indicates that dried pretreated bell pepper have better quality than dried untreated samples. This is because pretreatments like blanching improve its retention (Vega-Galvez et al., 2009). The results obtained are similar to that obtained by other authors working with peppers (Vega-Gálvez et al., 2009, Di Scala and Crapiste, 2008, Veras et al., 2011, Wiriya et al., 2009). The rehydration index increased with increase in drying temperature up to 80°C but decreased with a further increase in drying temperature to 90°C. Rehydration process depends on structural changes in vegetal tissues and cells of food material during drying, which produces shrinkage and collapse (Kaymak-Ertekin, 2002). This indicates that at higher drying temperature there is a greater structural change which results in more rapid rehydration. However the low rehydration index at drying temperatures of 90°C indicates that there is cellular structure damage in the dried pepper which results in modifications of osmotic properties of the cell as well as reduction in diffusion of water through the surface during rehydration (Kaymak-Ertekin, 2002). The rehydration indexes for the pretreatments were generally higher than that of the untreated pepper samples which shows that pretreatment aids and thus results in the occurrence of the greater cellular structural changes during drying.

Product colours and pungency are part of the quality parameters that need to be maintained during drying. The colour and pungency are considered to define the quality of dried pepper as these properties reflect the consumers' acceptance and therefore the market price (Hossain and Bala, 2007). The colour of the dried samples reduced with increase in drying temperature. This is similar to the results obtained by Vega-Gálvez et al. (2009) for red pepper in which the highest air-drying temperature (90°C) presented the lowest value of colour while the maximum was at air-drying temperature of 70°C. The colour content is mainly attributable to endogenous carotenoids thus the color content will be directly related to deterioration in these pigments due to high drying temperatures (Vega-Gálvez et al., 2009). The color of the pretreated dried pepper samples was generally higher than that of the dried untreated samples. This may be due to the fact that blanching reduces the enzymatic browning and prevents the loss of colour (Chung et al., 1992). The pungency for the different pretreatments was generally higher than that of the untreated samples while the pungency values for the drying temperatures were not generally significantly different. This indicates that the form of pretreatment employed has a greater effect on the pungency of the final dried product.

Table 8 Selected quality characteristics of pretreated and untreated bell pepper.

Sample	Temperature, °C	Ascorbic acid, mg/100 g DM	Colour, % transmittance at 40 µm	Pungency	Rehydration index, mL
SB		31.68±1.37a*	0.65±0.02d	6.8±0.5a	27.5±1.2ab
WB		20.24±3.29d	0.40±0.01f	5±0.71c	26±0.5b
PB	50	18.48±3.25e	0.55±0.03e	5.8±0.35b	24.2±0.6c
GB		17.60±1.98e	0.50±0.05e	4.8±0.27cd	22±0.9d
UB		15.84±2.51f	0.25±0.06h	3.8±0.33	23.3±0.3d
SB		28.81±1.28b	0.90±0.02a	6.4±0.57a	25±1.1bc
WB		28.16±1.33b	0.75±0.07c	6.0±0.6ab	25±0.4bc
PB	60	27.65±1.21bc	0.81±0.05b	3.6±0.31e	23.4±0.5d
GB		22.85±3.11cd	0.77±0.01c	3.8±0.21de	23.1±0.2d
UB		22.00±2.43cd	0.62±0.03d	3.6±0.28e	22.5±0.7d
SB		29.20±1.62b	0.78±0.01c	6.2±0.29ab	28.3±0.5a
WB		28.10±1.46b	0.46±0.08f	5.0±0.32c	27.1±0.8ab
PB	70	25.00±2.24c	0.33±0.05g	6.4±0.46a	27.5±0.9ab
GB		22.40±2.36cd	0.49±0.06ef	3.4±0.38e	27.5±0.7ab
UB		20.25±1.32d	0.28±0.03gh	5.0±0.22c	26.5±0.5b
SB		27.00±2.42bc	0.35±0.05g	6.0±0.38ab	33.4±0.7a
WB		28.16±1.21b	0.22±0.08h	6.4±0.19a	30.7±1.2a
PB	80	24.50±1.43c	0.30±0.09gh	4.2±0.55d	31.2±0.8a
GB		22.88±2.37cd	0.15±0.02i	4.2±0.62d	25.3±1.1bc
UB		22.60±1.42cd	0.10±0.01j	3.8±0.53de	29.1±0.2a
SB		21.12±1.33cd	0.40±0.03f	6.0±0.15ab	26±1.0b
WB		20.24±3.35d	0.25±0.04h	5.0±0.22c	25±0.5bc
PB	90	15.84±2.98f	0.20±0.01hi	4.8±0.41cd	25.3±1.0bc
GB		14.96±1.35fg	0.15±0.02i	5.0±0.27c	24.2±1.3cd
UB		12.91±1.52g	0.10±0.01j	4.4±0.14d	23±1.2d

Note: * Values are means of two determinations.

Values with same superscript in the same column are not significantly different ($P < 0.05$).

4 Conclusions

The effect of drying temperature and pretreatment on drying characteristics of bell pepper dried between 50°C and 90°C was investigated and the modeling of the thin-layer drying of the bell pepper was also carried out. The blanching pretreatment and increase in drying temperature was observed to decrease the drying time and subsequently resulted in a faster drying process. The Parabolic model was selected as the model that best describes the drying process for the bell pepper considered in this study. The energy consumption for pretreated samples was lower while values of the quality parameters for the pretreated samples were higher than that of untreated bell pepper. This indicates that blanching as a pretreatment optimizes energy consumption during bell pepper drying and results in products of higher quality.

Nomenclature

A tray area, m^2

c_a specific heat of air, kJ kg^{-1}°C^{-1}

D_{eff} effective moisture diffusivity, m^2/s

D_o constant (dimensionless)

D_t total drying time, h

E_a energy of activation, kJ/mol

E_{kg} specific energy requirement, kWh/kg

E_t energy needed, kWh

K_1, K_2 slope of straight line

L half of the slab thickness, m

M_e equilibrium moisture content of sample, kg water/ kg dry solid

M_i the initial moisture content, kg water/kg dry solid

M_{iw} the initial moisture content, kg water/kg wet material

M_t the moisture content at any time, kg water/kg dry solid

M_{tw} the moisture content at any time, kg water/kg wet material

M_R moisture ratio (dimensionless)

Rg universal gas constant, 8.3143 kJ/mol

T air temperature, °C

Tabs	absolute air temperature, K	R^2	correlation coefficient
W_o	initial weight, g	ρ_a	air density, kg/m^3
t	time of drying, s	ΔT	temperature differences, ^{o}C

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