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RESEARCH ARTICLE

EFFECT OF DRYING METHODS ON MOISTURE SORPTION, MICROSTRUCTURE AND OTHER QUALITY CHARACTERISTICS OF CHICKEN CUBES

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Abstract

Extended chicken cubes were dehydrated using freeze drying (FD), vacuum drying (VD), hot air drying (HAD) and solar drying (SD). The bulk density, colour and rehydration ratio varied significantly ($p \leq 0.05$) with the drying method employed. Rehydration ratio was highest for FD samples which exhibited highly porous microstructure. SD, VD, HAD samples exhibited flaky, fibrous and compact micro structures respectively showing significant variation in pore size and distribution. The sorption behaviour was analysed and different mathematical models were used to fit the sorption data. The sorption isotherms were Type II sigmoidal. GAB model gave the best fit to the experimental adsorption data of FD and VD chicken cubes while Peleg and Halsey models gave the best fit to the adsorption data of HAD and SD samples respectively. The study concludes that VD can produce chicken cubes with quality comparable to that obtained via FD and superior to HAD and SD samples.

INTRODUCTION

Extended meat products are popular in the world for economic reasons and they provide mixture of proteins and other nutrients to the consumers, which are desirable from nutrition point of view. Many ground, formed and whole muscle products rely on various non meat additives as binders, fillers or extenders to improve product characteristics and to reduce production costs. The selection of suitable binder has implications on the binding characteristics and hardness of the product. Modi and Prakash (2008), reported that pearl millets, carrots, cabbage, potato and skimmed milk powder were compatible in the formulation of meat cubes. Barbut (2006), studied the interactions between meat and non meat binders with respect to their contribution to meat gel microstructure. Milk proteins have been reported in many studies to exhibit functional properties as water and fat binders and have the potential to modify the textural characteristics of low fat meat products (Lucca and Tepper, 1994). Whey protein acts as fat mimetic which reduces food calorie but at high temperature it may undergo caramelization and denaturation (Anjaneyulu et al., 2013).

As of now, not many shelf-stable extended meat products are available in the market, so development and quality evaluation of an easily rehydratable, tasty, convenient and nutritious meat product will be of much significance. The development of meat product with incorporation of whey protein concentrate (WPC) can improve its nutritional quality, functional and textural properties. The available literature shows that not much work has been carried out in the area of restructured shelf stable chicken cubes containing WPC. Several drying technologies can be viable commercial options for manufacture of chicken cubes, including FD, VD, HAD and SD.

Water activity, probably is the most important single factor for determining the shelf-stability of most dried meats. Studies were undertaken to develop shelf stable processed meat products by applying freezing prior to fluidised bed drying process and two stage drying processes combining super heated steam drying with hot air drying or heat pump drying (Jayathilakan et al., 2007 and Nathakanekule et al., 2007). Each drying method has its own advantages and limitations. The final product obtained may differ in physico-chemical, nutritional, sensory and rehydration properties and microstructures (Caric and Calab, 1987; Caparino et al., 2012). As a result, by choosing the most suitable drying method and conditions, the final product quality and production costs can be controlled.

Conventional hot air drying requires high temperatures and long times and final products are characterised by low porosity and high apparent density values. Vacuum drying has been successfully applied to many fruits and vegetables and other heat-sensitive foods. Vacuum-dried materials are characterised by better quality retention of nutrients and volatile aroma. Apata et al., (2013), suggested that solar drying can be commercially exploited in tropics for production of dried Meat Product (Kilishi) due to high efficiency. Freeze drying is generally considered as the best method for production of high quality dried products with porous structure and little or no shrinkage, which can rehydrate readily before use. The retention of the nutrients and the aroma is high and a fresh-like product can be obtained (Ratti, 2001). But, it suffers from high production costs, high energy consumptions and low throughputs (Caparino, 2000; Ratti, 2001; Hsu et al., 2003).

Analysis of processes affecting physical, biochemical and microbiological stability of foods, which in turn determine their quality, is largely based on moisture sorption isotherms of the materials involved. These isotherms also reveal information about the sorption mechanism and interaction of food biopolymers with water. Finally, they are important in design and optimisation of unit operations such as preservation, drying, storing, packaging, and mixing (Tsami et al., 1990). Water sorption is one of the most important parameters that contribute to predict technological performance and product quality in foods on storage (Chirife and Buera, 1994; Vilades et al., 1995). The physical state of food solids has received increasing attention because of its importance in food processing and shelf life (Simatos and Karel, 1988).

Several empirical, semi-empirical or theoretical models can be used to describe mathematically the sorption isotherm for meats. The COST 90 study showed that most sorption isotherms of real foods could be expressed analytically by the GAB equation (Bizot, 1983). Furthermore, Peleg (1993), proposed a double power expression, which in comparison with the GAB equation yields a good or better fit of experimental data.

The present study was carried out to compare the effects of four different drying methods on the quality characteristics of dehydrated chicken cubes formulated with whey protein and corn flour. In this study, the effect of drying methods on physico-chemical properties, rehydration and moisture sorption characteristics of the chicken cubes was investigated. Scanning Electron Microscopy (SEM) as an image capture technique was used to find the relationship between drying methods and morphological changes of the chicken cube components.

MATERIAL AND METHODS

Preparation of chicken cubes

A process for the preparation of dehydrated chicken cube has been standardized at the laboratory. Chicken breast meat (pH 5.9) procured from Mysore local market was used for the present study. The chicken was manually deboned, was trimmed of any visible fat, chopped into small pieces, washed, marinated and cooked with addition of spices. The cooked chicken was mixed with WPC and corn flour and minced by using meat mincer (Sirman, Italy) fitted with 5 mm plate. The blend was minced at 1400 rpm. The minced mix was then formed into dough and shaped into chicken cubes of 1 cm thickness using a stainless steel mould and dried using various drying methods. The chicken cubes contained chicken solids: WPC: Corn flour in the ratio 60: 20: 20. The proximate composition of extended chicken cubes (with WPC) and control (without WPC) is shown in Table 1.

Drying of chicken cubes

One portion of the chicken cubes was pre frozen in a domestic freezer (-20°C) and subjected to freeze drying in a lab scale Lyodel freeze dryer (Delvac Pumps Pvt. Ltd., Chennai, India) at -40°C to 15 ° C for 24 h. The second portion of samples was subjected to vacuum oven drying at 70 °C for 24 h. The third portion of samples was subjected to hot air drying in a cabinet dryer for 13 h at 80°C. Fourth portion of chicken cubes were subjected to solar drying in a forced draft cabinet solar dryer for 21 h. All samples were dried to final moisture content below 5 % and packed in PFP pouches (45 GSM paper/20 µ Al. foil/37.5 µ LDPE).

Bulk density and colour change

Bulk density was determined by making the cubes fall freely into a measuring cup of 100 ml volume from a height of 10 cm and by weighing the contents of the cup. The colour were measured as L, a, b values using Hunter colorimeter (Hunter Lab, Reston, VA, USA) as given by Shand (2000). The colour change (ΔEc) of samples during drying was estimated using the equation 1.

$$\Delta Ec = \sqrt{(Li - Lr)^2 + (ai - ar)^2 + (bi - br)^2} \quad \text{......................(1)}$$

where Li, ai, bi are colour values of chicken cubes before drying and Lr, br, ar are colour values of rehydrated samples respectively.

Water activity and pH

Water activity was determined using water activity meter (Aqua Lab Decagon Devices Inc., Pullman, Washington USA). pH of the chicken cubes was determined using microprocessor controlled digital pH meter (Systronics, India)

Chemical quality and rehydration properties

The proximate composition and rehydration properties of the chicken cubes were evaluated using standard analytical procedures (AOAC., 1990 and Ranganna, 1986). Sample rehydration was performed in boiling water. The duration of rehydration was noted for each sample, as the time period after which there was no more absorption of water by the samples. Percentage rehydration was calculated using following expression

$$Rehydration\ (\%) = \frac{W_r - W_1}{W_0 - W_1} \text{ ----------(2)}$$

W_r = Weight of rehydrated sample (g)

W_1 = Weight of dried sample (g)

W_0 = Weight of fresh sample (g)

The rehydration ratio was calculated at fixed intervals of time by immersing chicken cubes into boiling water bath, rinsing excess water with kitchen towel and then weighing. The rehydration ratio was calculated using weight of sample before and after rehydration as follows

$$Rehydration\ ratio = \frac{W_1}{W_2} \text{.............(3)}$$

Where W_1 and W_2 are initial and final weight of dried chicken cubes respectively

Microstructure

Micrographs of chicken cubes were obtained using Scanning Electron Microscope (EVO LS 10 SEM , ZEISS, UK) by Gold/Pd sputter coating. Morphological analysis was carried out at high vacuum using operational voltage of 6KV and magnification of 500X.

Sorption isotherms

Moisture sorption as indicated by weight gain of chicken cubes were obtained using Dynamic Sorption Analyser (Q5000SA , TA Instruments, USA) under controlled temperature and humidity. Stepwise adsorption and desorption studies were carried out from 10-90% RH and back at a step interval of 10% RH at 25 °C. At each RH level equilibration was stopped when the relative change in weight gain remained below 0.01% for 5 minutes. Next RH was automatically applied. To establish moisture sorption isotherms, the equilibrium moisture contents were calculated and plotted against water activity.

Modeling of sorption isotherms

The different sorption models presented in Table 2 were chosen to fit the experimental sorption data because they are most widely used for several foods. Model parameters were estimated by taking the equilibrium moisture content to be the dependent variable. To calculate the equation parameters, a nonlinear regression analysis minimizing the residual sum of squares was applied within the range of 0.1–0.9 water activity. Various sorption models were evaluated for their suitability in predicting the sorption behaviour of the sample on the basis of the coefficient of determination (R^2) and reduced $\chi 2$ values and also on the basis of residual plots. The difference between the measured and predicted EMC values at various water activities were defined as residuals. The residuals were plotted against predicted values of EMC.

R^2 is the square of the correlation coefficient between the response values and the predicted response values. The adjusted R^2 statistic is generally the best indicator of the fit quality when additional coefficients are added to the model.

$$R^2 = \sum_{i=1}^{n} \frac{(x_i - \hat{x}_i)^2}{(x_i - \bar{x})^2} \text{ ....(4)}$$

Where x_i is the observed values of the dependent variable, $\bar{x}$ is its mean and $\hat{x}_i$ is the fitted value. Reduced $\chi 2$ is obtained by dividing the residual sum of squares (RSS) by the degrees of freedom (DOF).

Statistical Analysis

All experiments were repeated three times and data sets were subjected to analysis of variance (ANOVA) using the general linear models. Significant differences between the samples means were determined at the $p < 0.05$ levels by

ANOVA. The data consisting of equilibrium water contents at different temperatures and humidity levels were statistically analysed and the coefficients of various sorption equations were determined by means of standard regression technique using Origin Pro 8 software.

RESULTS AND DISCUSSIONS

Whey protein has beneficial effects on protein quality as well as functional characteristics and also serves as a fat replacer to obtain healthier meat products. Extended Chicken cubes were formulated with WPC (15-20%) and corn flour (20-40%). The whey protein exhibited a positive effect on the colour retention of chicken cubes during drying. The blend optimisation was carried out based on the sensory and rehydration properties of the product (data not shown). The optimised sample containing chicken solids, WPC and cornflour (60: 20: 20) and the control sample without WPC were analysed for proximate composition and the details are shown in Table 1. The extended chicken cubes contained lower fat and higher protein than control sample. In the case of hot air dehydration and freeze-drying of meat, lipid oxidation has been reported to be the major problem limiting the acceptability (Radhakrishna et al., 1988). The dehydrated chicken cubes with WPC are low fat products containing less than 10% fat and hence their shelf life is not limited by lipid oxidation as in the case of other meat products. The optimum sample was subjected to different drying methods and quality characteristics were compared.

Bulk density and colour

Significant difference was observed in colour and bulk density of chicken cubes prepared by different drying methods (Table 3). The bulk density was highest for SD sample followed by HAD, VD, and FD. This depends on the shrinkage and variation in drying times encountered for different drying methods. Solar dried samples showed case hardening with moisture retention in the interior. Freeze dried samples were lighter with low bulk density. The L (lightness) and b (yellowness) values were lower and a value (redness) was higher for HAD, VD and SD samples in comparison with FD samples. This may be attributed to comparatively longer exposure times to high temperature environment resulting in more browning as a result of reaction between amine groups of the proteins and available reducing sugars in connective tissue of chicken. Similar findings have been reported by Nathakaranekule (2007), in their comparative study on superheated drying techniques for chicken meat. In the present study, freeze drying yielded a lighter product with good colour. Hot air dried and solar dried samples were significantly different from the freeze dried product in terms of colour and bulk density. The vacuum dried chicken cubes were of comparable quality.

Rehydration characteristics

Rehydration ratio of dried chicken cubes indicated the capacity to absorb water and to hold soluble solids in dried matrix. It is clear from Table 3 that the rehydration ratio is significantly affected by drying method. The rehydration ratio is highest for freeze dried samples and lowest for solar dried samples. Large ice crystals formed by slow freezing is preferred since it promotes restoration of freeze dried chicken cubes. The low rehydration ratio of solar dehydrated chicken cubes may be explained on the basis that, the samples were exposed to temperatures for longer times during drying which might have induced changes in porosity and rehydratability. Generally rehydration ratio can be considered as a measure of structural damage caused by dehydration process which results in impaired reconstitution properties. The rehydration was 80-90% in case of freeze dried samples whereas in case of solar dried the rehydratability was very poor (50%). Hot air dried and solar dried samples were not rehydrated completely as moisture was not absorbed into the interior of the chicken cubes due to some case hardening. The solute losses from the cube matrix during rehydration can be another reason for this change. The variation in rehydration ratio with time is plotted in Fig. 1. This also showed significant differences between cubes obtained by different drying methods. Vacuum dried samples were comparable with freeze dried samples in quality, rehydratability and showed better retention of the meaty flavour than the solar dried and hot air dried samples.

Water activity and pH

Water activity (a_w) provides valuable information on the effects of water content on water availability in foods and on the physical state of food solids (Roos, 1993). Water activity, which is defined by the chemical potential of water, measures the availability of water for deteriorative changes or microbial growth. Water activity differed significantly ($p \leq 0.05$) based on the drying method used, the values increased in the order SD >VD> HAD > FD samples. Final moisture content and water activity play a major role in assessing the shelf stability of the product. Chemical, microbiological and sensory deterioration of the product has a direct correlation with the moisture content and water activity. Since the products under discussion has a moisture content of 3.2/100 g, which is less than the monomolecular layer value of meat (Attrey and Sharma, 1979), the deteriorative changes are expected to be minimum. pH of the samples did not differ significantly.

Microstructure

Microscopic analysis was performed to visualize the impact of drying methods on the microstructure of dehydrated chicken cubes. Micrographs of chicken cubes obtained using different methods of drying are shown in Fig 2. The variation in rehydration characteristics could be well correlated with the microstructure of chicken cubes obtained using different drying methods. The freeze dried chicken cubes possessed a highly porous honey comb like structure, consisting of larger pores (20-40 µm) distributed uniformly throughout the sample. Freeze-drying was carried out in two stages; the product is first slow frozen at -20°C and then the ice was removed by sublimation directly from the solid to the vapor phase.

During freeze drying, the sublimation of ice crystals grown within the chicken cubes leaves behind a spongy and porous structure. This type of porous structure is advantageous during rehydration. The porous structure will facilitate faster movement of water into the internal structure and decreases the rehydration and cooling time. In our analysis also, the percentage rehydration was 80-90% for freeze dried chicken cubes, which is the highest among other samples. Also the slow freezing rate and the high freezing temperature (-20 °C) used prior to freeze drying might have facilitated the formation of large ice crystals as reported by (Babic et al., 2009). Depending on the process conditions, pores or gaps with different characteristics are created by the ice crystals which sublimated. The absence of air prevents product deterioration caused by oxidation or chemical modification (Krokida, 1998; Anwar and Kunz, 2011). Lee et al., (1998), also noticed that freeze-drying method provided a dry product with porous structure as supported by scanning electron micrographs. Porosity of freeze dried meat was reported to be higher than air dried and vacuum dried samples (Maurer et al., 1972).

The microstructure of HAD chicken cubes showed dense, compact, rigid and continuous protein network characterized by small pores of size < 10 µm. In the case of conventional drying at higher temperatures, loss of moisture leads to the formation of voids, however they are not uniformly distributed throughout the matrix as in the case of freeze dried ones. The dense structure of HAD chicken cubes may be attributed to the temperature (75 °C) employed to avoid protein changes during the dehydration process. High temperature may cause protein denaturation and promote cross-linking of different proteins. Lack of uniformly distributed voids affected the rehydration capability in comparison with freeze dried sample.

It has been reported by earlier workers that HAD of food materials involving their prolonged exposure to high drying temperatures result in substantial deterioration of quality attributes (Maskan, 2000). High temperature drying may raise the hydrostatic pressure gradients of moisture between inside and outside of the dried samples and subsequently leads to large voids, resulting in crispy products. The evolution of water vapor inside the samples is the reason of pore formation after drying and pore development depends strongly on drying temperature (Fazelii et al., 2012; Prachayawarakorn et al,. 2008).

VD samples had similar pore size as FD samples. Some micro cracks were also observed in matrix which might have facilitated better rehydration of these samples. However the number of pores was lesser and their distribution in the protein network was not so uniform unlike FD samples. The surface morphology of solar dried chicken cubes was different from other samples due to its flaky appearance with very small pores < 8 µm. This explains the poor rehydratability of solar dried samples in comparison with other samples. Bondaruk et al. (2007), investigated the effect of drying conditions on the quality of vacuum-microwave dried potato cubes and found that in the case of HAD the intensity of structural changes depended on the drying temperature. Brown et al., (2008), found that carrot samples dried in ethano-modified supercritical carbon dioxide possessed many pores which could facilitate the movement of water into the internal structure and decrease the rehydration and cooking time compared with the air-dried samples. Similar results have been reported by Yang et al. (2010), who revealed that the larger porosity and total volume of the sample, the higher rehydration ratio.

The micrographs revealed larger pore size of FD samples. VD samples exhibited micro cracks facilitating moisture adsorption and better rehydration. HAD and SD samples appeared to have more compact and rigid matrix, did not have large pores or uniform pore distribution. Sorption studies were carried out to further establish the moisture adsorption characteristics of chicken cubes.

Sorption isotherms

Sorption isotherms of meat and meat products have been studied by many authors, with some considering the effect of temperature (Comaposada et al., 2000; Delgado and Sun, 2002a, 2002 b).

Fig. 3 shows the adsorption and desorption curves at 25°C for chicken cubes obtained using different drying methods. Each point is the average of three determinations. To estimate the sensitivity of foods to water vapor at different water activities, the shape of the sorption isotherm should be known as well as the critical points on the isotherm. It can be seen from figure that the sorption isotherms have a sigmoid or S-shape which is typical for most biological products and correspond to type II of the classification (Brunauer, et al., 1940).

The marking points defined by Heiss (1968), on the sorption isotherm are useful data in packaging and storage of food materials (Rahman, 1995). These marking points are temperature-dependent, therefore for their precise determination, knowledge of the storage conditions becomes important (Rizvi, 1995). The marking points consist of the initial point (Pi), the Pb point which marks the end of the first curved part of the isotherm, the critical point (Pcr) at which the food becomes unacceptable, and the end point (Pe) corresponding to the equilibrium with the ambient environmental atmosphere. The initial point Pi and end point Pe can be easily determined from the processing and storage conditions. For the great majority of foods point Pb lies in the range of aw between 0.15 and 0.25 (Rahman, 1995), the region of the sorption curves corresponding to a moisture water content between 14% and 19% and $0.5 < aw < 0.6$ may be considered as critical since the water uptake and the water availability as solvent is greater.

Fig 3 clearly shows that the equilibrium moisture content (EMC) for desorption was higher than that for adsorption, at a particular water activity. Hysteresis existed over the entire water activity range for SD, HAD and VD samples. Some thermodynamically irreversible processes must occur during desorption or adsorption. Polar sites in the molecular structure of the material are almost entirely occupied by adsorbed water in the wet condition. Upon drying and shrinkage, the molecules and their water holding sites are drawn closely enough together to satisfy each other. This reduces the water holding capacity of the material upon subsequent adsorption. The sorption isotherms of FD sample showed minimum hysteresis restricted to water activity ranging above 0.65. This indicates minimal changes during freeze drying which can result in better rehydratabilty of the product.

Modelling of sorption isotherms

The sorption curves for chicken curves are drawn as EMC against a_w (ERH). The effect of the four drying methods on the sorption isotherms, as shown in Fig 4 .These curves are used to estimate the coefficients of the different sorption models. Values of the various coefficients, regression coefficient (R^2) and reduced chi square ($\chi 2$) for all the three models fitted to adsorption data are presented in Table 4. It was found that Peleg model where Me and a_w represent equilibrium moisture content and water activity, respectively and other symbols are isotherm constants gives best fit to the experimental data of HAD chicken cubes, GAB model gave the best fit to the experimental sorption data of FD and VD chicken cubes and Halsey model gave the best fit to the sorption data of SD samples with highest values of R^2 and lowest values of chi square for a wide range of water activity.

Fig 5 shows the experimental and calculated values, using the best fit models, of equilibrium sorption isotherms at 25°C for the chicken cubes dehydrated with the four different methods. Each point is the average of two or three determinations. Fig 6 shows the residual plots for Peleg, GAB and Halsey models fitted to sorption data of chicken cubes. A model is considered acceptable if the residual values fell in horizontal band centered around zero, displaying no systematic tendencies towards a clear pattern. If residual plot indicates clear pattern, the model is not acceptable.

Boquet et al., (1978), reported that the Halsey (1948) and Oswin (1946) equations were the most versatile, and the Hailwood and Horrobin (1946) equation gave the best fit for meats. Our results for sorption behavior of HAD chicken cubes are in agreement with the findings of Delgado and Sun (2002b), who reported that the Ferro Fontan model followed by the GAB equation gave the best fit for the whole range of water activity and temperatures for chicken meat desorption. For meat and meat products, the GAB and Oswin models give reliable results at temperatures between 10 and 70 ◦C (Lind and Rask, 1991).The Peleg model seems to be the most suitable to describe the moisture sorption isotherm of HAD at 25°C, followed by GAB equation which also showed good fittings. One isotherm is well fitted by GAB equation when K is close to the unity. The fittings gave K value near to 1 for both vacuum dried and freeze dried samples. In overall evaluation, the good representation of the sorption data by the GAB model is not surprising because it is a semi-theoretical, multi molecular, localized, homogenous adsorption model and has been suggested to be the most versatile sorption model available. The constants of the GAB equation C and K are related to the energies of interaction between the first and further adsorbed molecules at the individual adsorption sites. Van den Berg (1981) stated that the parameters C and K incorporate the temperature effect. C is more enthalpic while K is more entropic in nature. A more detailed analysis of the GAB parameters can provide further valuable information about adsorption and desorption .Halsey model could not predict the sorption behavior of freeze dried and vacuum dried samples .However this model gave the best fit for solar dried samples. This indicates a clear difference in the adsorption characteristics of chicken cubes obtained using different methods.

For water activity up to about 0.2, most water molecules are strongly sorbed and almost immobilized, and thus behave in many respects like part of a solid (Van den Berg, 1981). Usually, this part of water is non freezable and therefore not available for chemical reactions or as plasticizers (Okos et al., 1992), which is normally considered to correspond to the monomolecular layer of adsorbed water (Xm) and has been suggested to be the critical water content above which deteriorative changes may occur. It should be noted that the critical water content is often slightly higher than the monolayer value (Roos, 1993). Delgado and Sun (2002 b), reported monolayer values for chicken meat 6.75-7.64 in the temperature range 20-30 ◦C. The isotherms obtained for chicken cubes prepared using different drying methods in the present study showed higher value of monolayer moisture content in the range 10 – 12 for desorption and 7-12 for adsorption .The higher values indicate better stability of these products compared to dehydrated chicken meat which may be attributed to the water binding ingredients and the cooking steps involved in the preparation of chicken cubes.

Freeze-dried product absorbed more water vapor than vacuum, hot air dried and solar dehydrated products. The freeze-drying method provides a dry product with porous structure and little or no shrinkage and with higher adsorptive capacity than the other methods (Yang and Atallah, 1985). But very rapid freezing (at -195°C) produces small ice crystals which result in a microporous structure (Saravacos, 1967) and a lower adsorptive capacity than the open porous structure of normal freeze-drying. The solar dried cubes have a lower adsorptive capacity than vacuum and hot air dried products. Solar energy is absorbed by the water molecules within the food material, causing slow evaporation and creating a less porous structure.

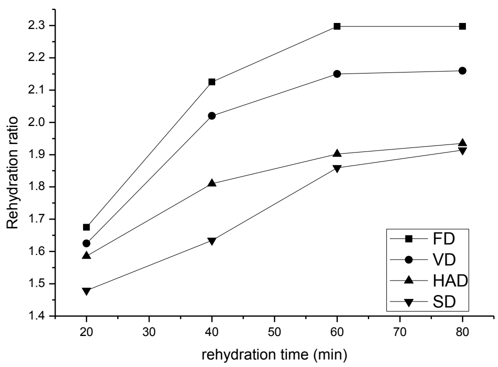
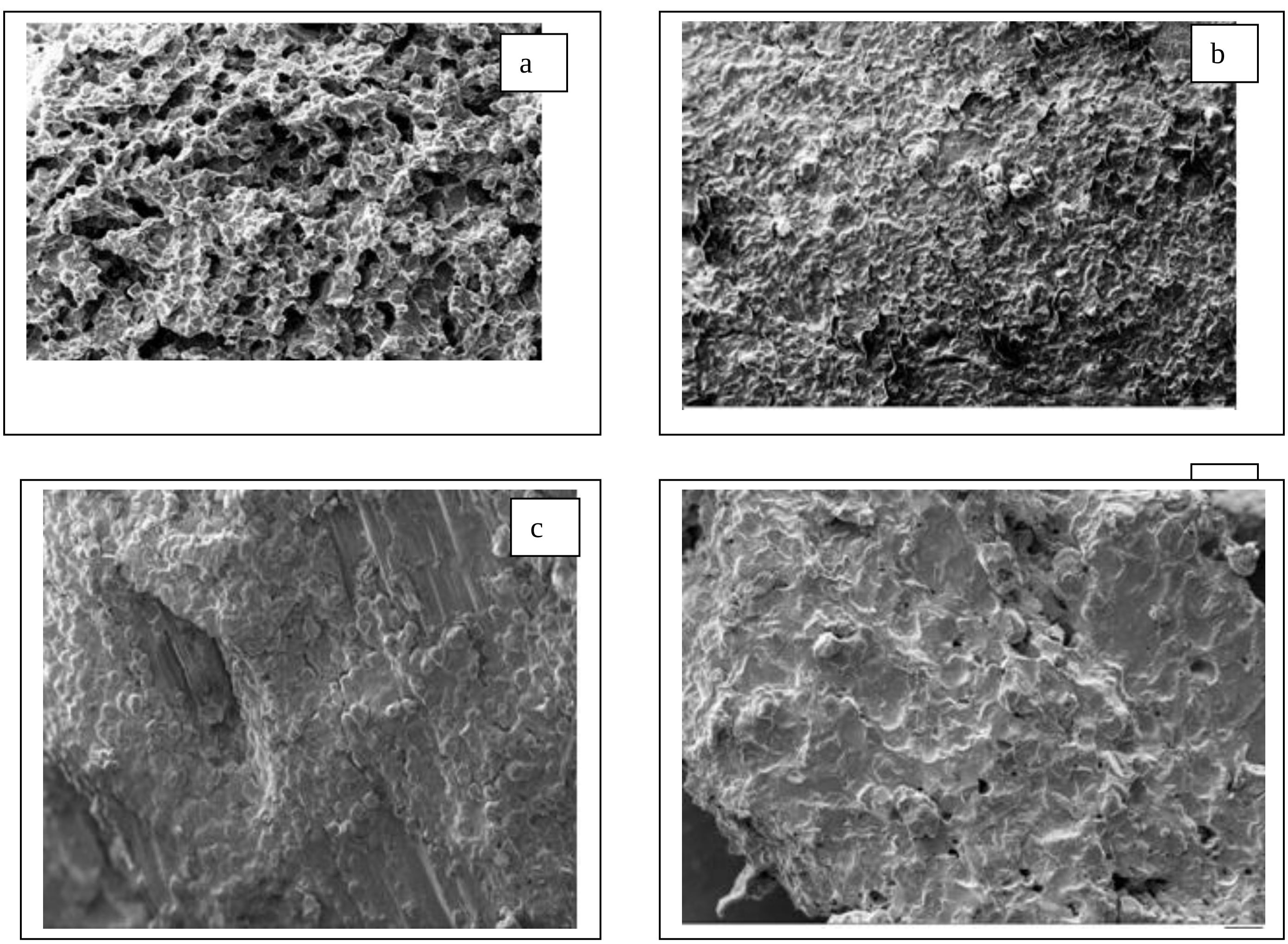


FIG. 1. VARIATION IN REHYDRATION RATIO WITH REHYDRATION TIME FOR CHICKEN CUBES OBTAINED USING DIFFERENT DRYING METHODS



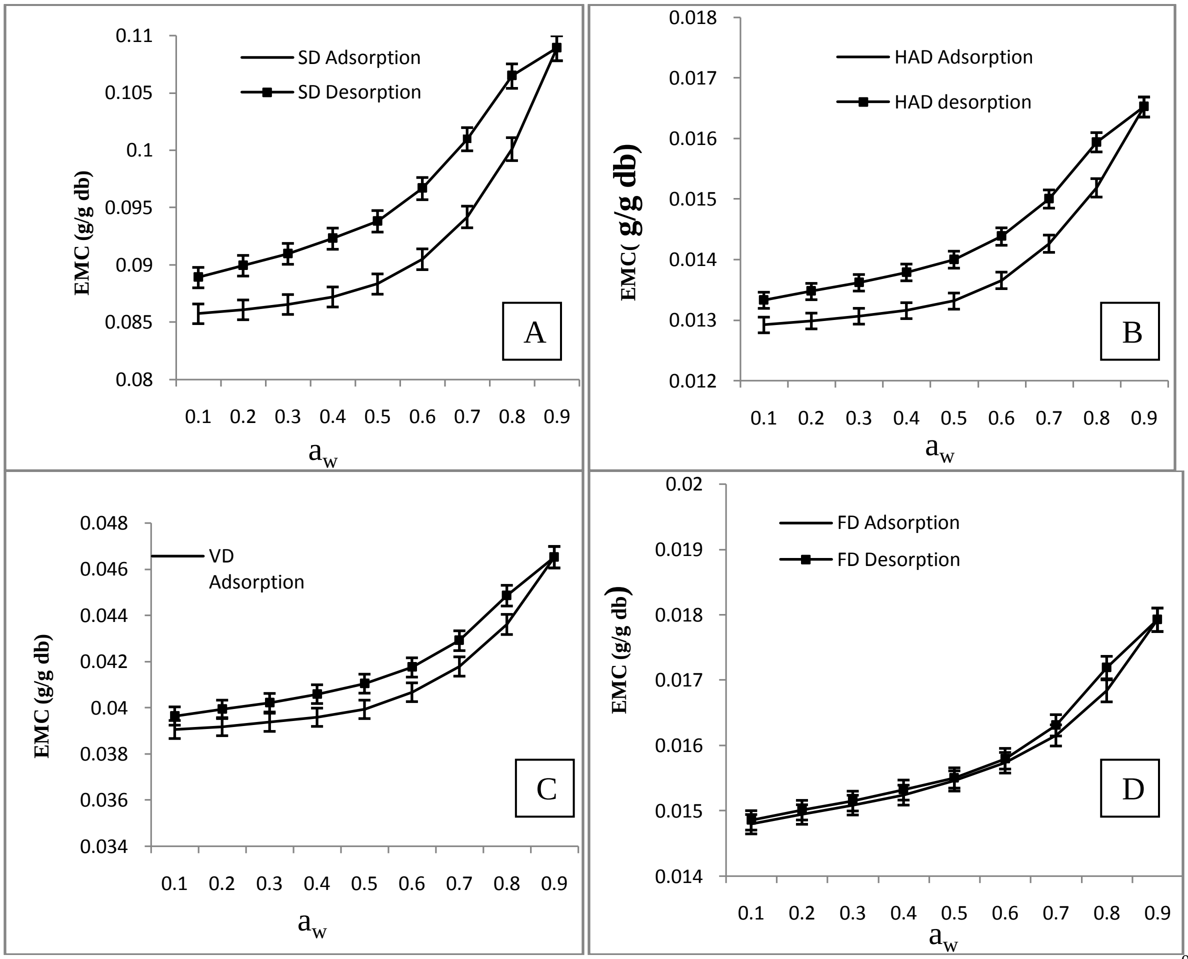


FIG .3. HYSTERESIS EFFECT OF (A): SD, (B): HAD, (C): VD AND (D): FD CHICKEN CUBES AT 25^{0}C

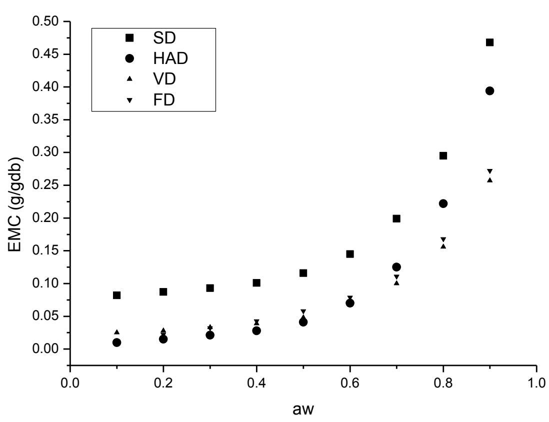
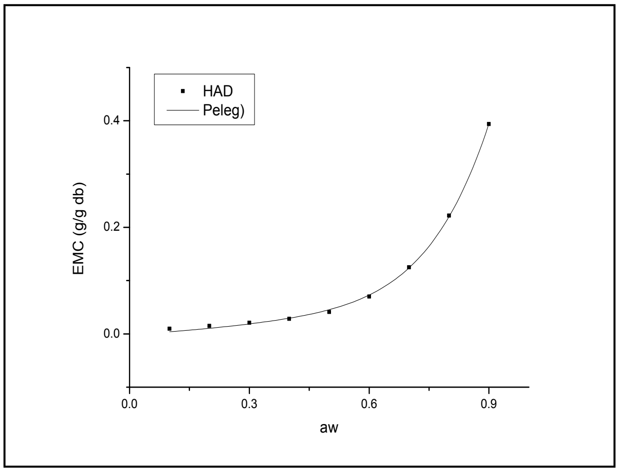


FIG . 4. ADSORPTION ISOTHERMS AT 25 C OF CHICKEN CUBES OBTAINED USING DIFFERENT DRYING METHODS



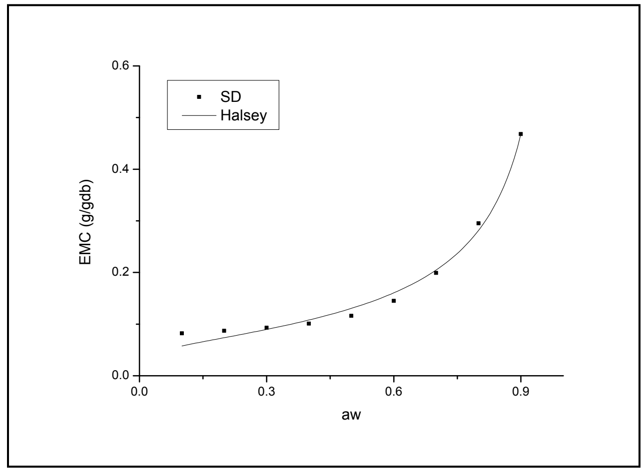
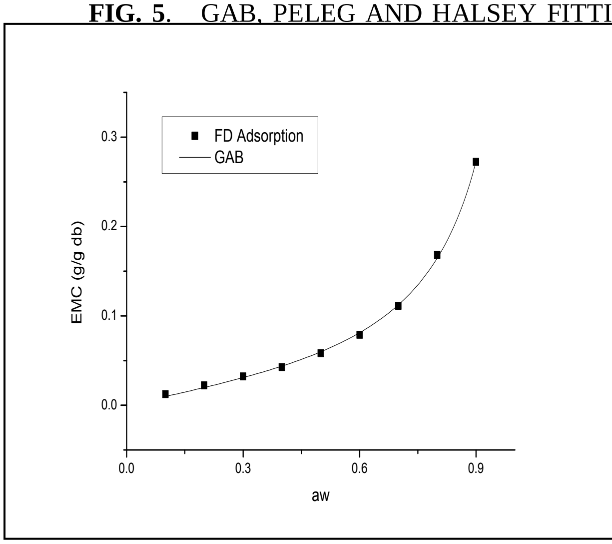
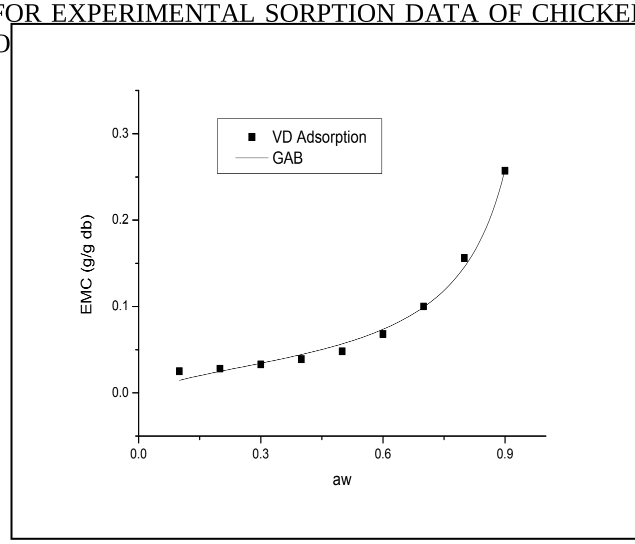
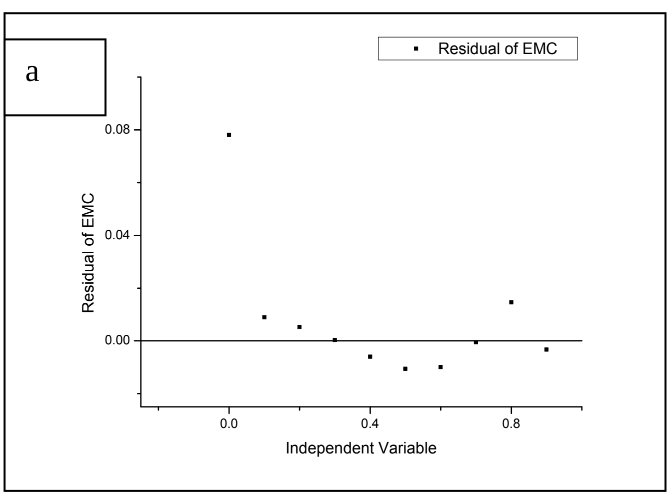


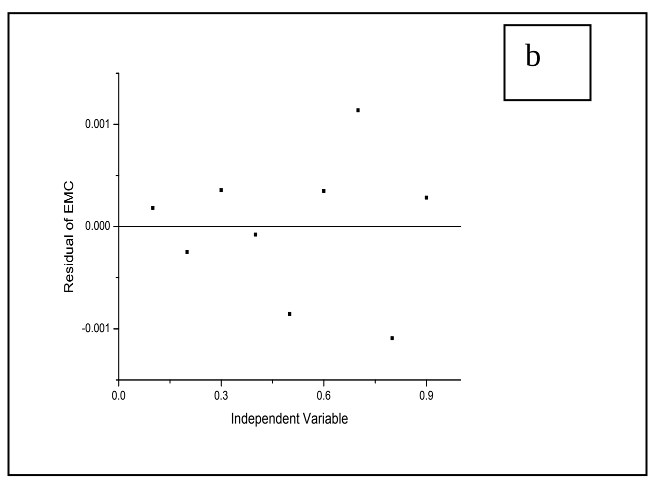
FIG. 5. GAB, PELEG AND HALSEY FITTINGS FOR EXPERIMENTAL SORPTION DATA OF CHICKEN

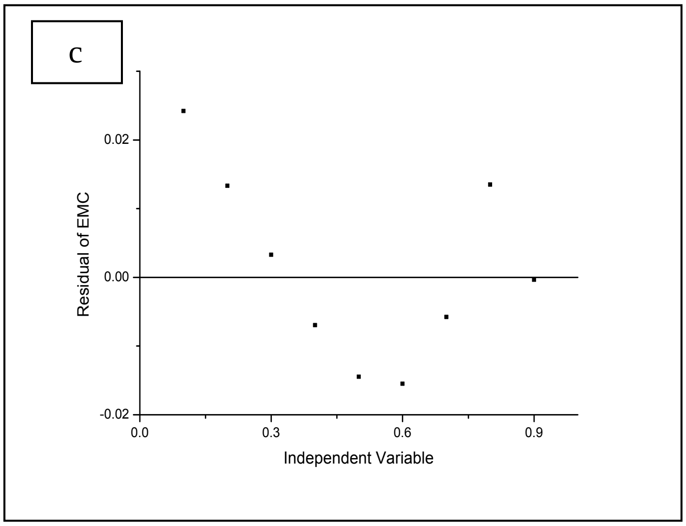
METHO N











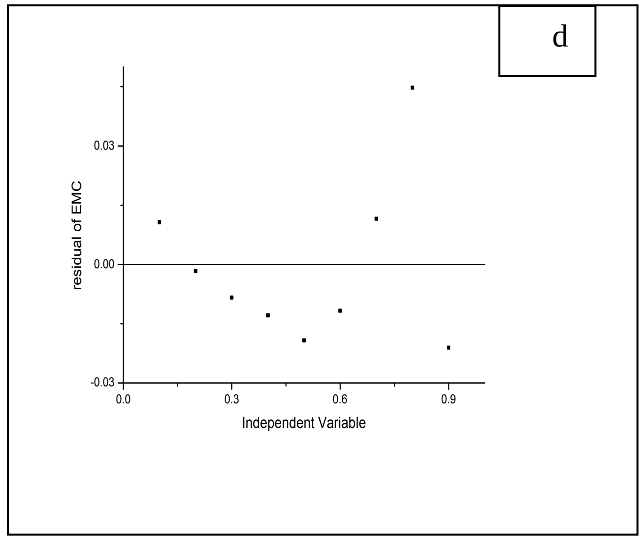


FIG. 6 . RESIDUAL PLOTS FOR THE MODELS GAB, HALSEY AND PELEG FOR CHICKEN CUBES OBTAINED USING (A) FREEZE FRYING (B) VACUUM DRYING (C) SOLAR DRYING (4) HOT AIR DRYING

TABLE 1: AVERAGE COMPOSITION OF CONTROL AND EXTENDED CHICKEN CUBES

Composition (%)	Control	Chicken cubes with WPC
Protein	20±0.1	31.75± 0.2
Fat	11± 0.2	5.38± 0.1
Carbohydrates	58.5±0.3	54.74± 0.3
Moisture	4±0.3	3.11± 0.2
Ash	6.5±0.2	4.56± 0.05
Energy Value	413 kcal/100g	398 kcal/ 100g

Values are shown as means ± standard deviation (n = 8).

TABLE 2. MOISTURE SORPTION ISOTHERM MODELS USED FOR ANALYSIS OF ERH-EMC DATA OF DEHYDRATED CHICKEN CUBES

Model	Mathematical Expression
GAB	$Me = X_m\ CKa_w/[(1\ \ Ka_w)(1\ \ Ka_w + CKa_w)]$
Peleg	$Me= K_1 a_w{}^{n1}+K_2 a_w{}^{n2}$
Modified Halsey	$Me = [\exp(A + Bt)/\ln(a_w)]^{1/C}$

Me, Xm, aw and t represent equilibrium moisture content, monolayer moisture content, water activity and temperature (C), respectively. The other symbols (A, B, C, K, K_1, K_2, n_1, and n_2) are isotherm constants.

TABLE 3. QUALITY PARAMETERS OF CHICKEN CUBES OBTAINED WITH DIFFERENT DRYING METHODS

	Solar dried	Hot air dried	Vacuum dried	Freeze dried
Bulk density (g/cm^3)	0.485^a	0.413^b	0.406^c	0.350^d
Colour values L*	60.02^a	60.29^a	59.2^b	73.52^c
a*	10.46^a	12.20^b	12.68^c	7.14^d
b*	37.14^a	33.96^b	36.86^c	39.52^d
Color change ΔE	13.46	15.60	12.67	24.88
Water activity (a_w)	0.503^a	0.273^b	0.317^b	0.105^c
% moisture	3.92^a	3.28^b	3.818^b	2^c
pH	5.53^a	5.53^a	5.8^a	5.83^a
Rehydration (%)	50^a	70^b	80^c	85^c
Rehydration ratio	1.7^a	1.87^b	2.13^c	2.29^c

* Values shown are average of 6 replications. Within raw, values superscripted with different letters are significantly different.($p \leq 0.05$).

TABLE 4. ESTIMATED PAAMETERS OF THE SELECTED MODELS FITTED TO ADSORPTION DATA FOR DEHYDRATED CHICKEN CUBES OBTAINED USING DIFFERENT DRYING METHODS

Model Parameters	FD	VD	SD	HAD
Peleg				
k1	0.1	0.0526	0.0812	0.092
k2	8.72	8.66	7.36	11.22
n1	0.2796	0.2639	0.44642	0.5477
n2	2.359	2.4799	1.8003	4.04648
R^2	0.96934	0.93982	0.81997	0.99008
Reduced χ^2	5.3E-4	9.4E-4	8.1E-4	9.3E-5
Modified Halsey				
A	0.1	0.2	0.1	0.1
B	0.130	0.133	0.11561	0.107
C	0.8125	0.81704	0.678	1.03
R^2	0.98743	0.981	0.991	0.97976
Reduced χ^2	9.8E-5	2.1E-4	8.4E-5	3.2E-4

GAB				
Xm	0.10655	0.07592	0.08949	0.08169
C	0.85805	5.65	2.135	1.803
K	0.97128	0.96537	0.81953	0.82925
R^2	0.9999	0.98129	0.85589	0.96816
Reduced χ^2	9.4E-5	1.04E-5	0.00228	6.1E-5

Me, Xm, aw and t represent equilibrium moisture content, monolayer moisture content, water activity and temperature (C), respectively. The other symbols (A, B, C, K, K_1, K_2, n_1, and n_2) are isotherm constants.

CONCLUSIONS

Whey protein concentrate is a promising additive for fat replacement, good water binding and improved textural quality of dehydrated chicken cubes. Extended chicken cubes containing WPC obtained using different drying methods having water activity less than 0.5 are shelf stable products. GAB model gave the best fit to the experimental adsorption data of FD and VD chicken cubes, Peleg and Halsey models gave the best fit to the adsorption data of HAD and SD samples respectively. Since the models cover a wide range of water activity they are of interest in predicting the shelf life behavior during storage at ambient temperature. The residence time, bulk density, colour and rehydration ratio also varied significantly ($p \leq 0.05$) with the drying method employed. Final moisture content and water activity values were highest for SD and least for FD samples. The bulk density was highest for SD sample followed by VD, HAD and FD. Freeze dried samples exhibited highly porous microstructure, Solar dried had a flaky appearance. VD samples had a fibrous micro structure and HAD samples showed more compact continuous protein network with small pores. Vacuum dried chicken cubes were comparable to freeze dried samples in terms of rehydration properties and showed similar moisture adsorption behavior. From the above studies, it could be concluded that the Vacuum Drying could be adopted successfully for the development of shelf stable chicken cubes with quality comparable to that obtained via freeze drying and better than Hot air dried and Solar dried cubes.

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