EFFECT OF PRETREATMENT AND AIR TEMPERATURE ON THE DRYING RATE, REHYDRATION CAPACITY AND COLOR OF ARTICHOKE

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ABSTRACT

EFFECT OF PRETREATMENT AND AIR TEMPERATURE ON THE DRYING RATE, REHYDRATION CAPACITY AND COLOR OF ARTICHOKE

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In this study, cleaned artichoke hearts belonging to three different ages were dried under constant external conditions at 50, 60 and 70°C using an air inlet velocity of 8.1 m/s. The sample to be dried was pretreated either by keeping it in distilled water or 1% (w/v) ascorbic acid or sodium bisulfite solutions for 30 minutes at the corresponding drying temperatures. Further, for comparison, the use of citric acid solution, increasing the concentrations of the solutions, reducing the pretreatment time, effect of degree of trimming and halving the samples were investigated.

The experimental drying rate data were treated to estimate the effective diffusivities and the effect of temperature together with the activation energy according to an Arrhenius type relation. For the product quality, rehydration capacity of the dried samples in water at 20°C as well as their color were determined.

As expected, the rate results indicated an increase in the drying rate hence the effective diffusivity with temperature for the distilled water and ascorbic acid pretreated samples. However, a reduction in the rate at the high drying temperature when sodium bisulfite solution used was attributed to the clogging of the pores by the precipitated solid due to rapid evaporation at the surface. Similarly, rehydration capacity and color of the water treated samples were enhanced with temperature where with the solution treated ones a reverse effect was observed. It is also found that the rehydration data could be well represented by Peleg equation.

Further, when citric acid solution was used for pretreatment, the results were quite identical to those of ascorbic acid. Also, increasing the ascorbic acid concentration to 2% (w/v) improved color whereas decreasing the dipping time increased discoloration. Finally, as an important parameter, the degree of trimming of the hearts proved to be highly effective on the rate and the other studied parameters as well as the post harvest and storage time.

Keywords: Drying, effective diffusivity, artichoke, rehydration, color.

ÖZ

ENGİNARIN KURUTULMASINDA ÖN İŞLEM VE HAVA SICAKLIĞININ ÜRÜNÜN KURUMA HIZI, SU ÇEKME SIĞASI VE RENGİ ÜZERİNE ETKİSİ

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Bu çalışmada üç değişik tarihte alınan soyulmuş ve temizlenmiş enginar göbekleri değişmeyen koşullarda 50, 60 ve 70ºC sıcaklıkta ve giriş hızı 8.1 m/s olan hava akımında kurutulmuştur. Kurumaya bırakılmadan önce 30 dakika süre ile kurutma sıcaklığındaki ya damıtık suda ya da %1'lik askorbik asit veya sodyum bisülfit çözeltisinde bekletilmişlerdir. Ayrıca, karşılaştırma amacı ile sitrik asit çözeltisi kullanımı, bekletme süresinin kısaltılması, soyma derecesi ve göbeği ikiye bölmenin etkileri incelenmiştir.

Deneysel kuruma hızı bulguları etkin su yayınganlığını ve Arrhenius türü bir ilişki ile sıcaklığın etkisiyle birlikte etkinlik enerjisini saptamakta kullanılmıştır. Ürünün niteliğini belirlemek için kurutulmuş göbeklerin 20ºC'deki su çekme sığası ile renkleri bulunmuştur.

Beklendiği gibi damıtık suda bekletilen göbeklerin kuruma hızı ve dolayısıyla etkin su yayınganlığı kurutma sıcaklığıyla artmıştır. Buna karşın sodyum bisülfit çözeltisinde bekletilen göbeklerde yüksek sıcaklıkta hızda bir azalma gözlenmiş ve bunun yüzeyde hızlı kuruma sonucu gözeneklerin çökelen maddece tıkanmasına bağlı olduğu düşünülmüştür. Benzer biçimde kurutulmuş göbeklerin su çekme sığası ve rengi damıtık suda bekletilen ürünlerde sıcaklıkla iyileşirken, çözeltide bekletilenlerde tersine davranış gözlenmiştir. Ayrıca, su çekme verilerinin Peleg denklemiyle açıklanabildiği bulunmuştur.

Ön işlemde sitrik asit kullanımı sonuçları askorbik asit kullanımının hemen tıpkısı olmuştur. Askorbik asit derişiminin %2'ye çıkarılması rengi olumlu etkilemiş ama daldırma süresinin kısaltılması renkte bozulmayı arttırmıştır. Hasat sonrası bekleme ve saklama süresinin ve göbeğin soyulması derecesinin önemli koşullu değişmezler olarak kuruma hızını ve öbür incelenen özellikleri etkilediği saptanmıştır.

Anahtar sözcükler: Kurutma, Etkin yayınma katsayısı, enginar, su çekme, renk.

To my parents...

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INTRODUCTION

1.1 Drying

Drying is commonly used to describe processes in which water is removed from a wet substance by applying energy. The term drying also refers to the removal of other organic liquids from solids. Therefore, drying may be defined as the removal of volatile substances from a mixture that yields a solid product. Commonly, the principal volatile substance is water (Keey, 1972; Geankoplis, 1993).

The reasons for drying are diverse. One of the reasons for drying the food material is the positive economic effect in transportation and storage provided by the reduction in product volume and weight without the need for refrigeration. The most evident reason for dehydration of food materials is preservation. Moisture contents of many food materials should be decreased to a prescribed value before being sold. Microorganisms that cause food spoilage cannot grow in the absence of water. Also, many enzymes cannot function without water. Dehydration also enables preservation of flavor and nutrition of the food where dried foods can be stored for extended periods of time (Keey, 1972; Geankoplis, 1993).

Broadly, drying methods can be subdivided by the way in which heat is supplied to the moist material and by the mode of operation, whether continuous or batchwise. Selection of whether batch or continuous is generally done according to production rates. Higher production rates (over 50,000kg/day) are best handled by continuous dryers.

There are four methods of heating: conductive, convective, radiative and dielectric. Most thermal dryers embody convective heating. The drying conditions are controlled by the temperature and the humidity of hot gas, which is generally air. Heat is supplied by the direct contact of the drying material with the hot air. The most common convective dryer is the tray dryer (Keey, 1972).

1.2 Enzymatic Browning

Most of the food products undergo browning due to enzymatic or nonenzymatic reactions that occur during processing and storage (Sapers, 1993). The reactions of amines, amino acids, peptides, and proteins with reducing sugars and vitamin C are nonenzymatic browning reactions (often called Maillard reactions) and with quinones are called enzymatic browning reactions (Friedman, 1996). Therefore, enzymatic browning can basically be defined as an initial enzymatic oxidation of phenols into slightly colored quinones which are then subjected to further reactions leading to brown, red or black pigment formation (Nicolas et al., 1994).

Enzymatic browning reactions in fruits and in some vegetables are initiated mostly by polyphenol oxidases (PPOs) and also peroxidases (E.C. 1.11.1.7) and laccases (E.C. 1.10.3.2). Polyphenol oxidase (1,2-benzenediol: oxygen oxidoreductase; E.C. 1.14.18.1 and E.C. 1.10.3.1) is a Cu-containing enzyme which is also known as polyphenolase, phenolase, catechol oxidase, catecholase, diphenol oxidase, *o*-diphenolase and tyrosinase. The enzyme catalyzes two distinct reactions: the hydroxylation of monophenols in *o*-diphenols (monophenolase or cresolase activity) and the oxidation of *o*-diphenols in *ortho*-quinones (diphenolase or catecholase activity). It is present in some bacteria and fungi, in all mammals and in most plants including wheat, tea, potato, cucumber, artichoke, lettuce, pear, papaya, grape, peach, mango and apple as well as in seeds such as cocoa (Martinez and Whitaker, 1995; Aydemir, 2003; Mayer and Harel, 1979; Whitaker, 1994; Nicolas et al., 1994).

In uncut or undamaged fruits and vegetables, the natural phenolic substrates are separated from polyphenol oxidase by compartmentalization within specialized organelles (Ashie et al., 1996). However, disrupting the cells promotes enzymatic browning, which produces undesirable colors and off-flavors. In addition to the aesthetic quality of fruits and vegetables, enzymatic browning also reduces nutritional quality through the destruction of nutrients such as oxidation of ascorbic acid (Hsu et al., 1988; Pizzocaro et al., 1993).

The control of enzymatic browning has always been a challenge to vegetable and fruit industry. Methods of inhibiting enzymatic browning can be generalized in three categories which include (1) temperature treatments such as chilling, freezing or heat inactivation of the enzyme by blanching, (2) lowering the water activity of the food by dehydration or salting, and (3) by chemical treatments. For controlling enzymatic reactions there are also novel techniques such as pressure treatment, enzyme treatment, ionizing radiation etc. (Nicolas et al., 1994; Ashie et al., 1996).

The most widely used approach to control enzymatic deterioration of food quality is the application of chemical inhibitors. The different ways of enzymatic browning control can be divided into three classes, depending on whether they mainly effect enzymes, substrates, or reaction products although in some cases two or three targets can be affected at the same time (Nicolas et al., 1994; Ashie et al., 1996).

Sulfite prevents browning by direct inactivation of the enzyme (PPO) with reduction of the Cu^{2+} to Cu^{+}, by interaction with intermediates in the browning process (quinone-sulfite complex), by combining with the reaction product (*o*-quinone) and reducing it back to the original phenols (*o*-diphenol) thus, stopping further reactions for discoloration. However, the presence of bisulfites (HSO_3^-) can be dangerous to human health since they can induce allergic reactions especially with asthmatic individuals therefore, sulfite alternative browning inhibitors are needed (Ashie et al., 1996; Sapers, 1993; Sayavedra-Soto and Montgomery, 1986).

Ascorbic acid (vitamin C), is probably the best known alternative to sulfites since inhibition of browning occurs by reduction of *o*-quinones back to phenolic compounds before they can undergo further reaction to form pigments. It has GRAS (generally recognized as safe) status for use as chemical preservative (Sapers, 1993; Dziezak, 1986).

Citric acid is an inhibitor of browning reaction in a way different from ascorbic acid since it makes a complex with the enzymatic copper (Cu^{2+}), thus affecting on the enzyme itself. It is more effective when combined with antioxidants such as ascorbic acid. It is also regarded as GRAS by FDA (Food and Drug Administration) (Dziezak, 1986; Pizzocaro et al., 1993).

Blanching techniques are often operated within temperature ranges of 60 to 105°C or higher. Blanching treatments can be performed by exposing vegetables to hot water, steam or microwaves from several seconds to minutes. The primary objective of blanching is to reduce enzyme activity to a level which no noticeable change occurs in the product during subsequent handling. However, blanching can expel undesirable flavors and also some desirable flavors may be lost during blanching (Ashie et al., 1996; Severini et al., 2003).

1.3 Artichoke (*Cynara scolymus* L.)

A native of the Mediterranean, the artichoke is a perennial in the thistle group of the sunflower family. It is a member of the Compositae (sunflower) family, so named because the members have small flowers (florets) born in dense composite heads that resemble single flowers. The artichoke was used as food and medicine by the ancient Egyptians, Greeks, and Romans; in Rome, the artichoke was an important menu item at feasts. Common names for the artichoke are globe artichoke, alcachofra, alcachofera, artichaut, tyosen-azami.

The artichoke plant, *Cynara scolymus*, is a thistle-like, herbaceous perennial with strong, prickly, deeply-cut leaves and large terminal heads of violet, blue, or white flowers. It is grown for the flower heads, which are harvested before they bloom. In full growth, the plant grows to a height of 0.9 to 1.2m and spreads to cover an area about 0.1 to 0.15m in diameter. Peak season is March through May and again to a smaller degree in October. The Green Globe artichoke prefers temperate climates, never too hot or cold. The central coast of California, where winters are relatively frost-free and summers are cool and moist with fog, is an ideal growing area. The largest and most of the smallest artichokes are sold to the fresh market. About one-fourth of the crop is used for canned artichoke hearts and frozen, quartered artichokes (Seelig and Charney, 1967; Anonymous, 2004b; Taylor, 2004).

Artichoke has been used in traditional medicine for centuries as a specific liver and gallbladder remedy. In Brazilian herbal medicine systems, leaf preparations are used for liver and gallbladder problems, diabetes, high cholesterol and hypertension, anemia, diarrhea (and elimination in general), fevers, ulcers, and gout. In Europe it is also used for liver and gallbladder disorders; in several countries, standardized herbal drugs are manufactured and sold as prescription drugs for high cholesterol and digestive and liver disorders. Other uses around the world include treatment for dyspepsia and chronic albuminuria (Taylor, 2004).

Artichoke contains approximately 85% moisture, 10% carbohydrate, 3% protein, 1% vitamins and minerals. It has only 47kcal in 100g of serving due to its low fat and high moisture and dietary fiber content. It supplies most of the vitamins and minerals to the diet (Table A.1). The artichoke is rich in dietary fiber and is characterized by the absence of starch as polysaccharide reserve. Especially the artichoke heart is a good source of insoluble (18.11%) and soluble (26.74%) dietary fiber (Lopez et al., 1996).

Total phenolic contents of approximately 1.2% (w/w) on a dry matter basis revealed that artichoke pomace is a promising source of phenolic compounds that might be recovered and used as natural antioxidants or functional food ingredients

(Schutz K, et al., 2004). The artichoke is popular for its pleasant bitter taste which is attributed mostly to a phytochemical called cynarin found in the green parts of the plant. Cynarin (1,5-*O*-dicaffeoylquinic acid) is considered one of artichoke's main biologically active chemicals. It occurs in the highest concentration in the leaves of the plant, which is why leaf extracts are most commonly employed in herbal medicine. Phenolic composition has medicinal value since it has antihepatotoxic, choleretic, diuretic, hypocholesterolemic and antilipidemic properties. Other documented "active" chemicals include flavonoids, sesquiterpene lactones, polyphenols and other caffeoylquinic acids (Taylor, 2004, Sanchez-Rabaneda et al., 2003).

The residues of the canning industry, which is the most important consumer of this crop, can form up to 60% of the harvested plant material. The common disposal of artichoke raw material is used as organic mass, animal feed, and fuel and fiber production. However, owing to the antioxidant capacity of polyphenols and their possible implication in human health in prevention of cancer, cardiovascular diseases and other pathologies, in the present, artichoke raw materials are being subjected to chemical analyses for their phenolic composition (Sanchez-Rabaneda et al., 2003).

Free and/or bound phenolic compounds are widely distributed in the vegetable kingdom and their amounts vary greatly with the plant part. The metabolism of phenolics is further compartmentalized and changes in their relative amounts can be expected to occur during different stages of plant development. Phenolic compounds have been implicated in several important biological phenomena such as the germination of seeds and plant growth, the resistance of plants against phytopathogens, activation or inhibition of enzymes, and the quality of foods. In addition, phenolics play an important role in the browning response of plant tissues on cutting or injury. For the same reason artichoke heads, which are economically very important in Mediterranean areas, have received attention with respect to their phenolic composition (Lattanzio and Van Sumere, 1987).

The fact that quality and shelf life of artichoke heads, whether stored at 4°C or at room temperature, are affected by the development of unpleasant colors and flavors and loss of nutrients, brought the necessity of researches on this. Since PPO is located in the cytoplasm of the artichoke heads as a soluble enzyme, and is found responsible for being the catalyst of discoloration reactions, importance is given to it the most (Aydemir, 2004; Leoni et al., 1990; Espin et al., 1997).

1.4 Dehydration of Vegetables

Food dehydration dates back several centuries. The first known record of drying involved vegetables and appeared in the 18th century. Thereafter development of the drying industry was closely related to war scenarios around the world. British troops in the Crimea (1854-1856) received dried vegetables from their homeland, Canada and US followed the same way during the wars. By 1919, among the products processed in the US were green beans, cabbage, carrots, celery, potatoes, spinach, sweet corn, turnips and soup mixtures (Vega-Mercado et al., 2001).

Because fruits and vegetables are a valuable micronutrient resource, dehydration technologies should also ensure maximum nutrient retention. Although mineral content of fruits and vegetables is stable to dehydration, the vitamins are highly labile and are destroyed through enzymes. Together with the product quality, storage stability and rehydration characteristics should also be considered for the dried foods (Gomez, 1981).

There is no information on artichoke drying in the literature. However, there is a need for this research since artichoke cannot be cultivated in winter due to the need for temperate climates and since it has high contribution to human diet. About one-fourth of the crop is used for canned artichoke hearts and frozen (Anonymous, 2004b) therefore, drying artichoke becomes an important concept since it is a relatively inexpensive method of preserving food.

1.5 Diffusion of Moisture in Solids

In general, food dehydration refers to the removal of moisture from a food product. Basically, water may be held in a food product in two ways as unbound and bound. Water in the interstitial spaces and within the pores of the material are held by purely physical force related to surface tension. This type of water is called unbound water which exerts the same vapor pressure and possesses the same latent heat of vaporization as does pure water at the same temperature. It is related to physical structures of the product. Another portion of water may be held on the internal and external surfaces of the solid material by interactions between the water molecules and the solid material to form mono or multi-layer of water molecules. This type of water is bound water. It exerts less vapor pressure and possesses greater heat of vaporization than the pure water at the same temperature. It is closely associated with the chemical structures of the product. Free moisture is the excess of the equilibrium moisture content (X^*) of the product. It depends on the type of the product, temperature and water vapor concentration of the air. Only the free moisture content can be removed during a dehydration process (Keey, 1972; Chung and Chang, 1981).

Dehydration process can be divided into two major rate periods; the constant-rate and the falling-rate. If the product is initially covered with a thin film of unbound water, evaporation will take place from the surface when it is exposed to relatively dry air. The rate of the evaporation is independent of the solid. Since evaporation of moisture absorbs latent heat, the liquid surface will come to, and remain at, an equilibrium temperature where the rate of the heat flow from the surroundings to the surface exactly equals the rate of heat absorption. If the solid is porous, most of the evaporated water is supplied from the interior. The rate of evaporation remains constant until the average moisture content reaches a value X_c, the critical moisture content. This period of drying is known as the constant-rate period. It may be missing entirely, depending on the type and the initial moisture content of the product. The rate of drying is mainly affected by inlet temperature, humidity, and flow rate of the air. (Treybal, 1981; Geankoplis, 1993; Chung and Chang, 1981)

When the average moisture content of the solid reaches the critical moisture content, the surface film of moisture is so reduced that further drying causes dry spots to appear on the surface. These spots occupy larger portions of the exposed surface as drying proceeds. This is the first part of the falling-rate period, the period of unsaturated surface drying. Ultimately, the original surface film of liquid is entirely evaporated. The rate of drying is also affected by temperature, humidity and the velocity of air in this period (Treybal, 1981; Chung and Chang, 1981).

On further drying, the plane of evaporation slowly recedes from the surface. Heat for the evaporation is transferred to the zone of vaporization. Vaporized water moves through the solid into the air stream. In this period, diffusion in the solid controls the rate of drying. Thus, rate at which moisture can move through the product, as a result of concentration gradients existing between the internal parts and the surface of the solid, is the controlling step. The rate of internal movement of the moisture decreases more rapidly than before as the moisture content of the solid is lowered by drying till the equilibrium moisture content X* is reached, where the drying stops. This is the second part of the falling-rate period and known as the internal diffusion-controlling step. The main drying process takes place in the falling rate period. In the falling rate period, the drying rate depends mainly on the physical structure and chemical composition characteristics of the solid (Treybal, 1981; Geankoplis, 1993; Chung and Chang, 1981; Yusheng and Poulsen, 1988).

For porous media transport, the work of Luikov suggests that temperature (T), moisture content (X) and gas pressure (P) are primary variables and the equations are;

$$\frac{\partial T}{\partial t} = K_{11}\nabla^2 T + K_{12}\nabla^2 X + K_{13}\nabla^2 P \tag{1.1}$$

$$\frac{\partial X}{\partial t} = K_{21}\nabla^2 T + K_{22}\nabla^2 X + K_{23}\nabla^2 P \tag{1.2}$$

$$\frac{\partial P}{\partial t} = K_{31}\nabla^2 T + K_{32}\nabla^2 X + K_{33}\nabla^2 P \tag{1.3}$$

where t is time and K_{mn} values are coefficients.

The contributions of two distinct variables on the transport of the third variable are presented in these equations. In Eq. 1.2, it can be seen that the mass transfer is determined not only by the differences in the concentration of matter, but also by thermal (Soret effect) and momentum diffusion. The effect of thermal diffusion on the mass transport is known as the Soret effect. In convective drying, due to the small influences of thermal and momentum diffusion on mass transport, Luikov's equations can be simplified (Keey, 1972). Therefore, Eq. 1.2 reduces to;

$$\frac{\partial X}{\partial t} = K_{22}\nabla^2 X \qquad 1.4$$

This equation is another form of the Fick's second law (Bird et. al., 1960);

$$\frac{\partial X}{\partial t} = \nabla\left(D_{eff}\nabla X\right) \qquad 1.5$$

where D_{eff} (m^2/s) is the effective diffusivity, which is an overall transport property that includes the effects of all possible mechanisms of transport of moisture in both liquid and vapor form. It combines several transfer mechanisms such as capillary flow, transfers due to heat and pressure gradients, gas and liquid diffusion etc. The solution of Eq. 1.5 for a slab (thickness 2L) under the conditions of constant moisture diffusivity, uni-directional diffusion, negligible external mass transfer resistance and negligible volume change upon moisture loss using the initial and boundary conditions of (Crank, 1975; Tütüncü and Labuza, 1996);

$$\begin{array}{lll} X(L,0) = X_0 & & t = 0 \\ X(2L,t) = X^* & \text{at} & x = 2L \\ X(0,t) = X^* & & x = 0 \end{array}$$

results in;

$$\frac{X_t - X^*}{X_0 - X^*} = \frac{8}{\pi^2}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(-(2n+1)^2\frac{\pi^2 D_{eff}t}{4L^2}\right) \qquad 1.6$$

Here, X_t is the moisture content at time t, X^* is the equilibrium moisture content, X_0 is the initial moisture content, L (m) is the half thickness of the slab and the group $D_{eff}t/L^2$ is the dimensionless Fourier number for the mass transfer. When Fourier number is greater than 0.1, the terms other than the first can be ignored and taking the natural logarithm of both sides condenses the relation into the form:

$$\ln\left(\frac{X_t - X^*}{X_0 - X^*}\right) = \ln\left(\frac{8}{\pi^2}\right) - \frac{\pi^2 D_{eff}}{4L^2}t \qquad 1.7$$

Equation 1.7 provides the determination of D_{eff}/L^2 from the semi-log plot of $(X_t-X^*)/(X_0-X^*)$ versus t.

The effective diffusivities of some materials follow an Arrhenius type of equation as;

$$D_{eff} = D_0 \exp\left(\frac{-E_a}{RT}\right) \qquad 1.8$$

where E_a is the activation energy (kJ/kg mol), T is temperature (K), R is the gas law constant (kJ/kg mol K) and D_0 is a constant.

Eq. 1.8 can be put into the linearized form of:

$$\ln(D_{eff}) = \ln(D_0) - \frac{E_a}{RT} \qquad 1.9$$

This enables determination of E_a and D_0 from the semi-log plot of D_{eff} against 1/T.

1.6 Water Absorption during Soaking

One of the quality factors considered for drying food systems is the rehydration capacity during soaking. Soaking is a long process in which time to reach constant weight is usually in the order of 24-48 hr. The conditions of soaking may affect cooking, nutritional qualities and physical properties of end products therefore, characterization of soaking is needed for practical applications. Water absorption in soaking process needs to be predictable as a function of time and temperature (Hung et al., 1993; Peleg, 1988). Thus, understanding the theory of water absorption of a dehydrated product is practically important.

The mathematical analysis of experimental data for water absorption during soaking, thus understanding the water transport in food materials, was mainly based on Fick's law of diffusion. However, the complexity of the process and the requirement for the numerous functions and parameters resulted in a simpler and an empirical equation derived by Peleg (1988). The equation was not derived from any set of physical laws or diffusion theories. It has been used to predict long range water intake from experimental data obtained over a short time under isothermal conditions to model water absorption of food materials (Sopade et al., 1992; Hung et al., 1993; Sayar et al., 2001; Pinto and Esin, 2004).

Peleg (1988) proposed a two parameter, non-exponential empirical equation,

$$X_t = X_0 + \frac{t}{k_1 + k_2 t} \qquad 1.10$$

where; X_t is the moisture content at time t (t>0), X_0, the initial moisture content (t=0), and k_1 (Peleg rate constant) and k_2 (Peleg capacity constant) are constants. The units of k_1 and k_2 correspond to the moisture and time units. Thus, if X_t and X_0 are given in percent by weight on dry basis and the time unit is in hours, then the unit of k_1 will be hour per weight percent on dry basis and that of k_2 will be reciprocal of weight percent on dry basis.

From Eq. 1.10 when $t \rightarrow \infty$, the equilibrium moisture content X^* is obtained as:

$$X^* = X_0 + \frac{1}{k_2} \qquad 1.11$$

The momentary sorption rate dX_t/dt is simply obtained by taking the derivative of Eq. 1.10 with respect to time, t:

$$\frac{dX_t}{dt} = \frac{k_1}{(k_1 + k_2 t)^2} \qquad 1.12$$

From Eq. 1.12, the initial rate, i.e., at t=0 is $1/k_1$

Eq. 1.10 can be transformed to a linear relationship in the form:

$$\frac{t}{X_t - X_0} = k_1 + k_2 t \qquad 1.13$$

Eq. 1.13 implies that a plot of $t/(X_t-X_0)$ against t gives a straight line with k_1 as the ordinate-intercept and k_2, the slope of the line. By such a plot, the characteristics of the Peleg constants can be studied. The constant k_2 can be considered to characterize the water absorption parameter of a food material, which does not significantly change with the temperature. It is also inversely related to the absorption capacity since the lowest water absorption capacity has the highest k_2 (Sopade et al.,1992; Turhan et al., 2002). Studies in the literature concluded that k_1 is a function of temperature described by an Arrhenius type equation:

$$\frac{1}{k_1} = k_0 \exp\left(\frac{-E_a}{RT}\right) \qquad 1.14$$

where k_0 is a constant.

Eq. 1.14 can be used to define the temperature dependence of the reciprocal of that constant. Also, $1/k_1$ is called the initial rate of absorption thus, at a given temperature, as k_1 decreases, the amount of water absorbed becomes greater (Sopade et al., 1992; Hung et al., 1993; Turhan et al., 2002).

1.7 Objectives of the Study

Drying is one of the oldest ways of preserving food materials and it is a significant step in the processing of many food systems. Drying of artichoke is an important conceptual work since artichoke cannot be cultivated in winter season due to the need for temperate climates. Also there is insufficient artichoke -canned or frozen- in the market. Therefore, drying artichoke is considerable due to the fact that it is a relatively inexpensive method of preserving food.

The objective of this study is to investigate the effects of pretreatment and air temperature on the drying characteristics of artichoke under constant external drying conditions and to determine the rehydration quality of dried artichokes. Since there is no information on artichoke drying in the literature, this can be seen as a preliminary work on drying of artichokes.

Drying behavior of artichokes at different temperatures, by applying various pretreatments and by determining the rehydration quality, was investigated. For this purpose, experimental drying rates, rehydration rates and color as quality attribute were compared. Rehydration behavior and the effective diffusivities were calculated and correlated using approved and accepted relations.

CHAPTER 2

MATERIALS AND METHODS

2.1 Artichoke (*Cynara scolymus* L.)

Fresh artichokes were purchased from a local market. They were stored as whole in a cold room at 0ºC with 84% RH for 2-3 weeks. Since the experiments lasted more than three weeks, artichokes used were obtained in three different periods (A, B, C; each indicating one period). Differences between A, B and C purchased artichokes and the effects of storage time on the quality of the product were also experimentally determined.

Artichokes, prior to the pretreatment and drying, were first peeled from the outer shells and then the inner feathers were scraped off. This remaining part is called as artichoke heart. Due to this manual processing of the artichoke, there might had been some differences between the samples. In order to see the effect of these cleaning processes, experiments were also performed. Half of an artichoke and a deeply scraped artichoke were also dried, soaked and color determinations were made. Since the storage time seemed to be long enough for the deterioration of the vegetable, one of the artichokes purchased at the beginning (A) was stored for 2.5 months and it was compared with the one presently bought (B) where group C indicates the last purchasing period. One artichoke was halved and the half was dried at 60ºC where the other was dried at 25ºC till equilibrium and the data were also compared.

2.2 Moisture Content Determination

Moisture contents of artichoke hearts were determined using the standard gravimetric method (AOAC, 930.04, 1995). Artichoke heart prepared from a lot was weighed in a balance (Sartorius, sensitivity; 0.01g, PT120, Germany) and put in a petri dish (115mm diameter). It was then placed in a lab oven (Dedeoğlu, TS5050, Turkey) adjusted to 100ºC and kept there (over night) until constant weight was attained. This was done in duplicate for each of the purchased artichoke groups (A, B, C).

2.3 Pretreatments

Prior to subjecting an artichoke heart to drying, one of the three main pretreatments was applied. These were, i) water treatment (dipping in distilled water), ii) dipping in 1% (w/v) ascorbic acid ($C_6H_8O_6$) (Merck, H233174, Germany) solution, iii) dipping in 1% (w/v) sodium bisulfite ($NaHSO_3$) (Sigma, S9000, USA) solution and blanching them at the drying temperatures (50, 60, 70ºC) for 30 minutes at the same time.

In order to see the effect of citric acid on browning of artichoke, at 50ºC, 1% (w/v) citric acid ($C_6H_8O_7$) (Merck, G4271, Germany) solution was also used. Additionally, blanching time was decreased to 15 minutes to see if color, drying and rehydration rates were affected by this parameter. Also artichoke was treated with 2% (w/v) sodium bisulfite and 2% (w/v) ascorbic acid solutions in order to check if color was affected by increasing the concentration. Since the temperatures were kept moderate and time was longer compared with the industrial applications (mostly boiling water for several seconds to minutes) of blanching, prevention of browning was not theoretically the basic reason for the use of blanching in the experiments. It was done in order to attain the steady-state condition for drying and in order to increase the penetration of the solutions into the food material. Blanching was proceeded with the aid of a water bath with a shaker (Clifton, Nickel Electro Ltd., England), which was preheated to the required temperature before the fresh artichoke was soaked. The pretreatments used can be summarized as follows:

- Dipping in 1% (w/v) sodium bisulfite solution while keeping it at the corresponding drying temperature (50, 60, 70ºC) for 30 minutes.
- Dipping in 1% (w/v) ascorbic acid solution while keeping it at the corresponding drying temperature (50, 60, 70ºC) for 30 minutes.
- Dipping in distilled water (water treated) while keeping it at the corresponding drying temperature (40, 50, 60, 70ºC) for 30 minutes.
- Dipping in 1% (w/v) citric acid solution while keeping it at 50ºC for 30 minutes.
- Dipping in 2% (w/v) sodium bisulfite solution while keeping it at 60ºC for 30 minutes.
- Dipping in 2% (w/v) ascorbic acid solution while keeping it at 60ºC for 30 minutes.
- Dipping in 1% (w/v) sodium bisulfite solution while keeping it at 60ºC for 15 minutes.

2.4 Batch Drying

For the drying experiments, the laboratory batch dryer shown in Figure 2.1 for drying under constant external conditions was set up. It consisted of a drying chamber (air inlet diameter: 5cm, chamber diameter: 10cm), a balance (Sartorius, sensitivity; 0.01g, PT120, Germany) and a fan (Professional 1500, TS322, Hong Kong) for air supply. Air supplied by the fan, first passed through an electrical heating zone and then over the sample, attached vertically to the balance.

An adjustable electrical heater was used as the heat source to attain the required air temperature. The balance connected to the drying chamber with a sample holder was used to measure the weight of sample as a function of time. Velocity of the air at the chamber inlet was measured by an anemometer (Turbo Meter, Davis Instruments, USA) and it was kept constant at 8.1m/s. Dry and wet bulb temperatures were determined by a psychrometer (Cole-Palmer, W.3312-40, USA). The relative

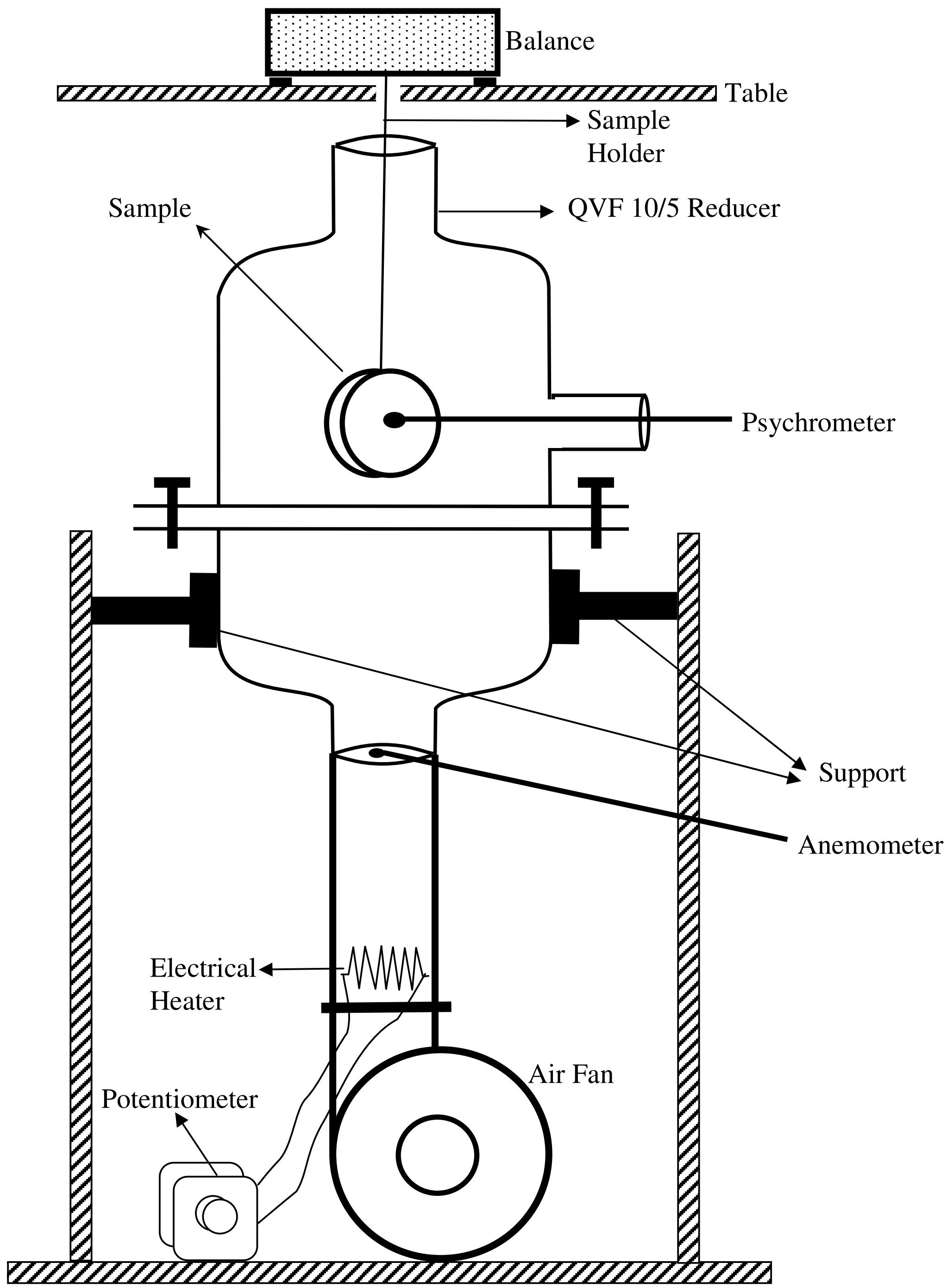


Figure 2.1 Schematic Drawing of the Laboratory Batch Dryer

humidity and the absolute humidity of the air were determined with the aid of a psychrometric chart by using wet bulb and dry bulb temperatures (Treybal, 1981).

Before starting any drying experiment, the system was heated to the steady-state drying temperature at the desired value. When the system reached steady-state, and the artichoke heart was ready after the applied pretreatment, the sample was placed into the drying chamber and drying was started. Dry bulb temperatures of 50, 60, and 70ºC were used for the dehydration of artichoke hearts. 40ºC was also tested for the water treated sample. Data were taken at 5, 10, and 20 minute-intervals until the equilibrium weight was reached.

2.5 Water Absorption of Dry Artichoke Hearts

Each dried artichoke heart was soaked in 300ml distilled water at 20ºC. The weight data were taken at 5, 10, and 20 minute-intervals. For each time interval, the sample was taken out and the excess water was gently wiped with a fresh paper towel. It was then weighed and placed back into distilled water. This procedure was applied until the moisture content about 80% (wet basis) was attained. Some samples were left over night and the rehydration capacity at the end of 24 hours was measured.

2.6 Color Measurement

Colors of the 78% (wet basis) rehydrated artichoke samples were measured by using a colorimeter (Minolta, CR10, Japan). Due to the fast discoloration, color was measured via cutting the brown surface. The data were taken over the whole surface through rotation of the artichokes and the mean values were recorded considering the inside and the outside parts of the artichoke heart separately. Hunter L, a, b parameters were used as the color scale where L value represented lightness (100 for white and 0 for black), a value signified greenness and redness (-60 for green and 60 for red) and the b value represented the change from blueness to yellowness (-60 for blue and 60 for yellow). L (lightness), ΔE (total color change), and BI (browning index) values were taken into account for the determination of product quality. Where;

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \tag{2.1}$$

$$BI = \frac{[100(x - 0.31)]}{0.17} \tag{2.2}$$

$$x = \frac{(a + 1.75L)}{(5.645L + a - 3.012b)} \tag{2.3}$$

The browning index (BI) represents the purity of brown color and is reported as an important parameter in processes where enzymatic or nonenzymatic browning takes place (Palou et al., 1999). L and BI are also put into normalized form as ΔL (L-L_0) and ΔBI (BI-BI_0). L_0, a_0 and b_0 denote the reference values which were obtained from the fresh sample.

CHAPTER 3

RESULTS AND DISCUSSION

Drying under constant external conditions helps to find out the drying characteristics of a food material. Using the kinetic weight data obtained from the experiments, drying zones and the effective diffusivities in the diffusional zone can be determined, giving the drying behavior of the food material.

3.1 Air Drying of Artichoke

Since artichoke is a valuable source of nutrients and has a limited crop season, an alternative to canning can be drying. The drying characteristics of artichoke is not present in the literature therefore, this study can be a preliminary research on this. For this purpose, drying temperatures of 50, 60, and 70ºC were selected.

The drying data are given in Appendix C Tables C.1.1 to C.4.4. From the plot of dimensionless moisture content against time, the effect of temperature on the water treated artichoke samples can qualitatively be observed (Figure 3.1).

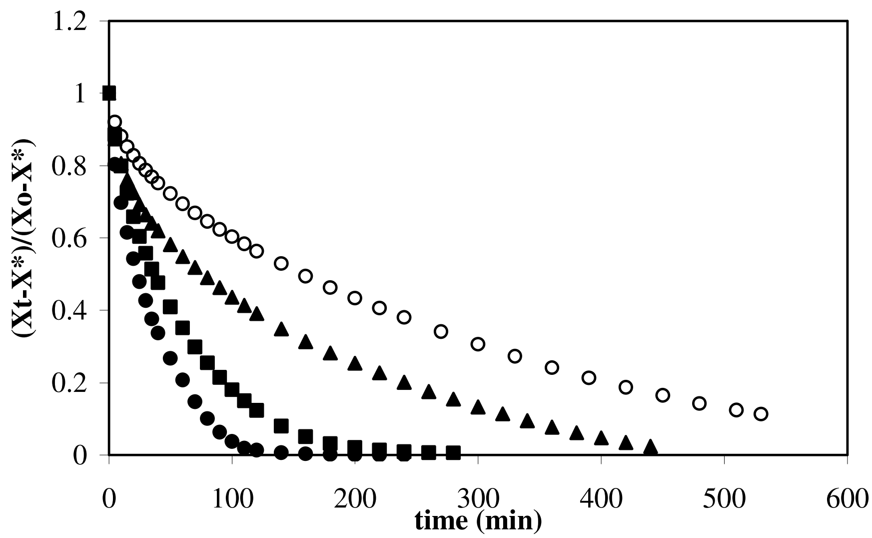


Figure 3.1 Drying curves for water treated samples at the studied temperatures.
(○) 40ºC (▲) 50ºC (■) 60ºC (●) 70ºC

Figure 3.1 indicates a decrease in the drying time with increasing temperature under constant air humidity and constant air flow rate which as well signifies an increase in the effective diffusivity and the drying rate of water treated samples.

3.1.1 Effective Diffusivities

The psychometric data for the temperatures used in the drying experiments and for the air at the surroundings are given in Appendix B Table B.3 and Table B.2, respectively. The equilibrium moisture contents of the samples at these temperatures were not available in the literature so equilibrium weights were determined from the drying rate data upon termination of drying. By using the data in Appendix C Tables C.1.1 to C.4.4 and with the aid of Eq. 1.7, the curves to calculate the effective moisture diffusivities were plotted. The curves for the water and solution treated samples are shown in Figures 3.2 to 3.8.

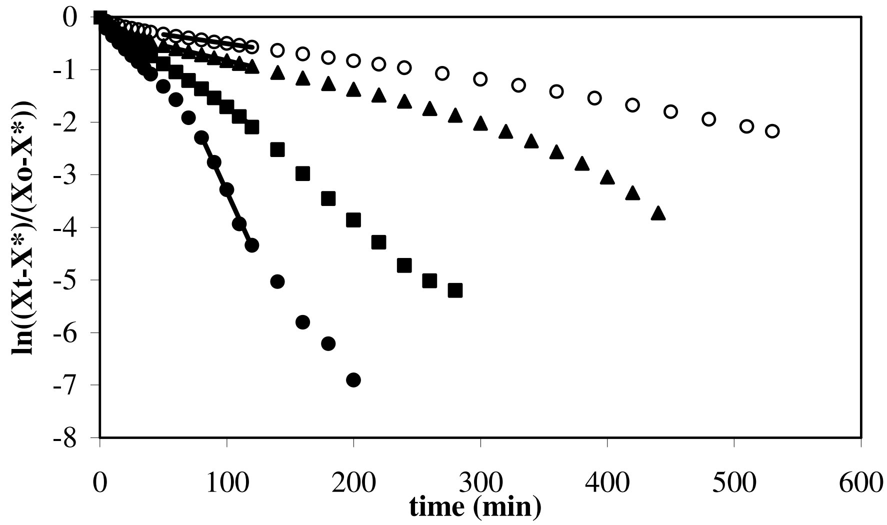


Figure 3.2 Variation of dimensionless moisture content with time for the water treated samples at different drying temperatures.
(○) 40ºC (▲) 50ºC (■) 60ºC (●) 70ºC

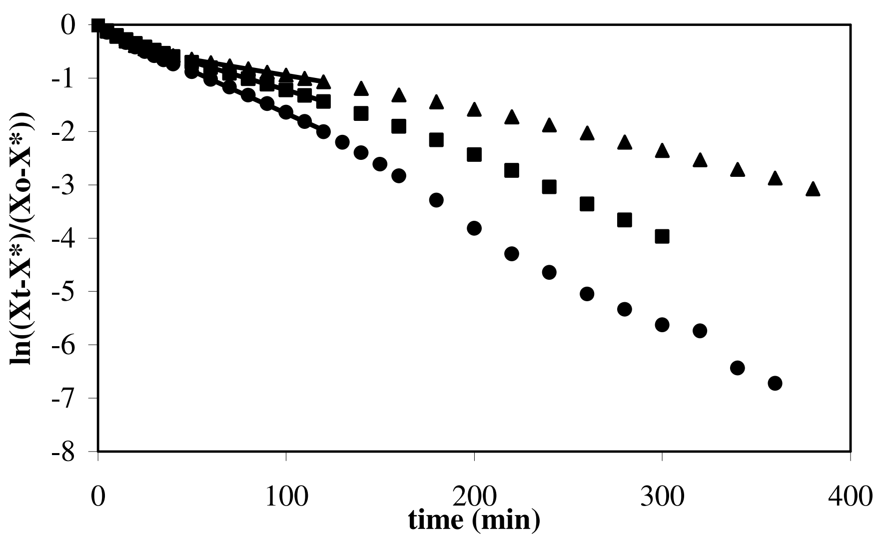


Figure 3.3 Variation of dimensionless moisture content with time for samples treated with 1% ascorbic acid solution at different drying temperatures.
(▲) 50ºC (■) 60ºC (●) 70ºC

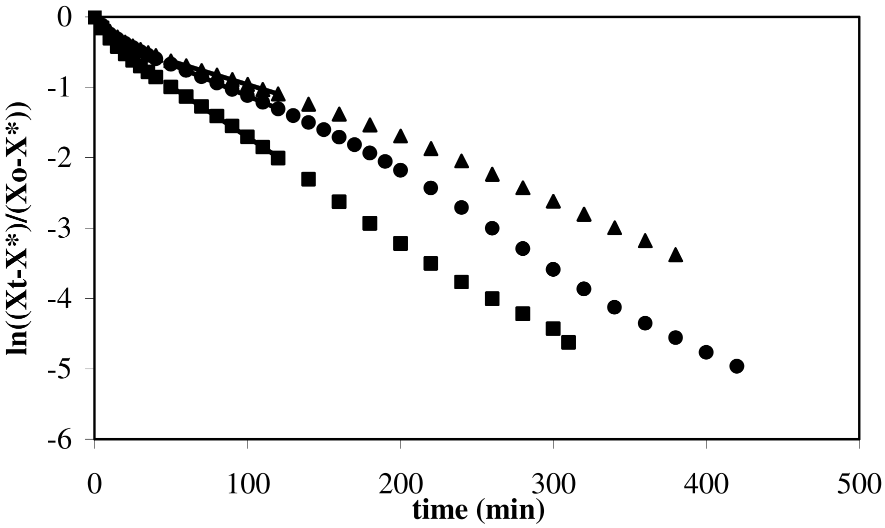


Figure 3.4 Variation of dimensionless moisture content with time for samples treated with 1% sodium bisulfite solution at different drying temperatures.
(▲) 50ºC (■) 60ºC (●) 70ºC

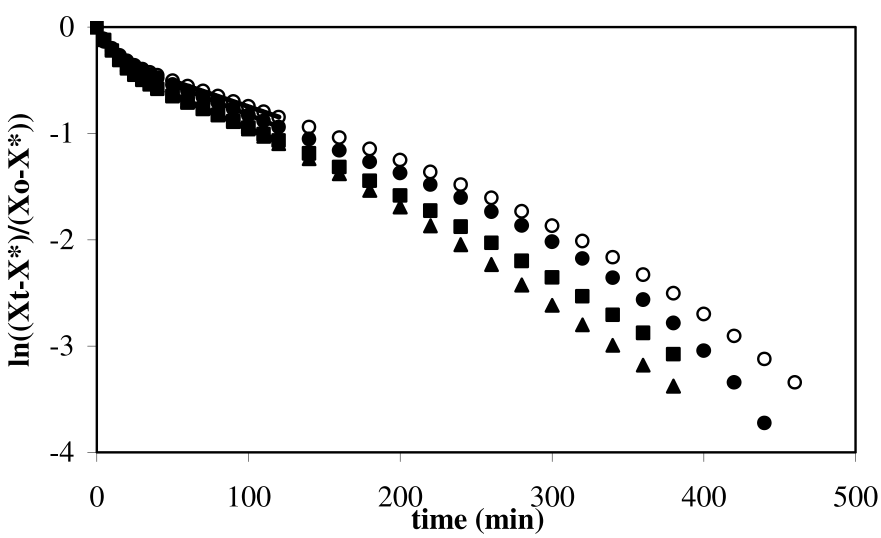


Figure 3.5 Variation of dimensionless moisture content with time at 50ºC for different pretreatments.
(▲) 1% sodium bisulfite (■) 1% ascorbic acid (●) water treated (○) 1% citric acid

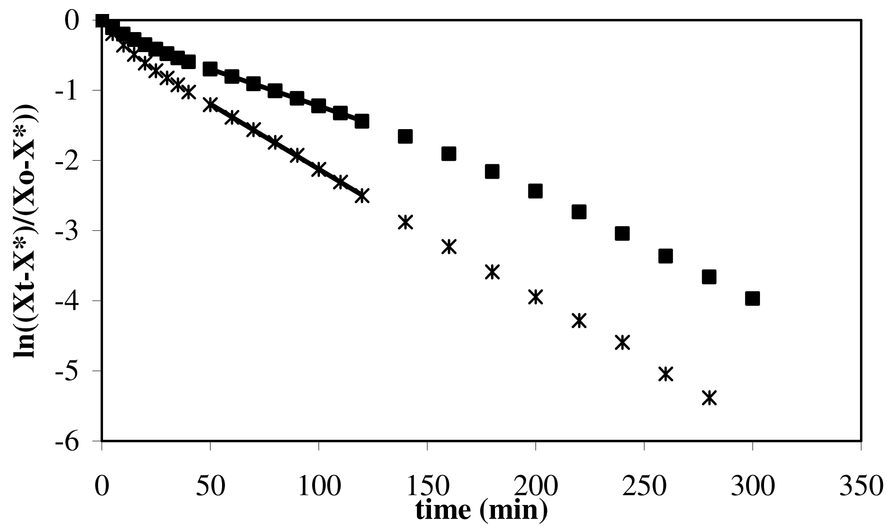


Figure 3.6 Effect of ascorbic acid concentration on the drying rate at 60ºC.
(■) 1% (*) 2%

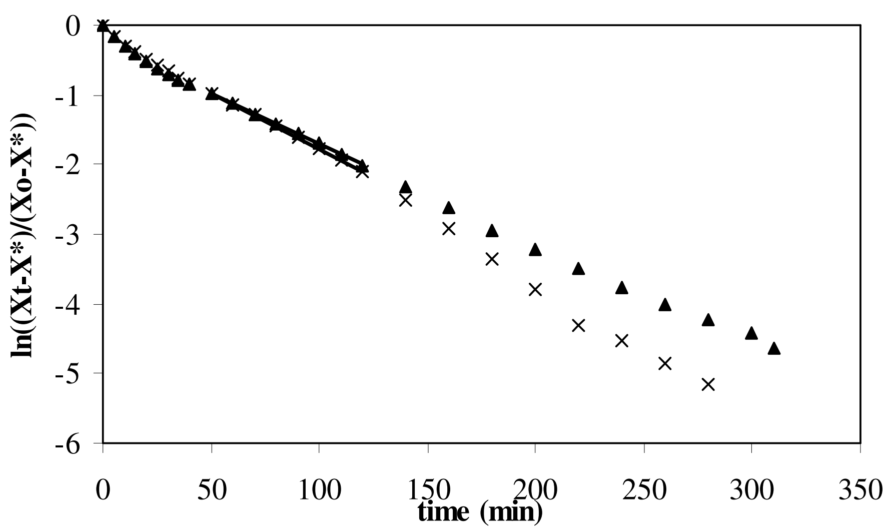


Figure 3.7 Effect of sodium bisulfite concentration on the drying rate at 60ºC.
(▲) 1% (x) 2%

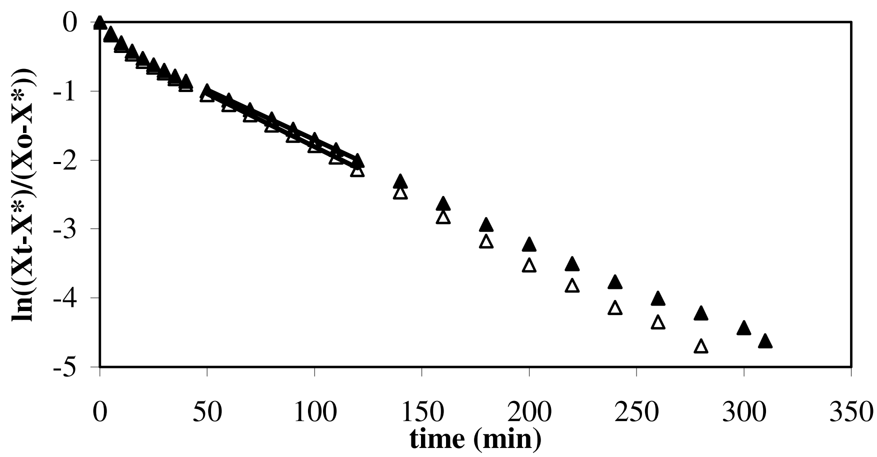


Figure 3.8 Effect of treatment time on the drying rate at 60ºC.
(▲) 1% sodium bisulfite (30min) (Δ) 1% sodium bisulfite (15min)

Inspection of the figures indicates that during drying of the artichoke samples the constant rate period ended within few minutes. This might be due to relatively high temperature of the samples from the pretreatment and high flow rate and temperature of air. It can be seen that there occurred minimum two diffusional zones. The existence of two or more falling rate periods might be due to case hardening since migration of soluble solids to the surface and high surface temperature resulted in a barrier to moisture migration until formation of surface cracks (Maskan, 2001).

For the first linear portions of the curves, slopes of the lines were determined by regression analysis and D_{eff}/L^2 values were calculated. The effective diffusivities were calculated as D_{eff}/L^2 as artichoke hearts were not uniform in size, shape and structure. Further, artichoke samples had high initial moisture content and due to this reason, considerable shrinkage took place as drying proceeded. Therefore a characteristic dimension could not be defined. In order to disregard the shrinkage effects, as a comparative value, only the first falling rate zone was used to estimate D_{eff}/L^2. The results are tabulated in Table 3.1. As a means of comparison, the effective diffusivities of water in dehydrated potato and ethanol are in the order of

10^{-10} and 10^{-9} m^2/sec (Yusheng, 1988; Geankoplis, 1993), respectively which is in conjunction with the findings by estimating the thickness as 1cm as an average value.

For Eq.1.7 to be applicable in calculation of the effective moisture diffusivity, Fourier number ($D_{eff}t/L^2$) was also considered and it was found to be greater than 0.1 for all cases since time was relatively long enough.

Table 3.1 D_{eff}/L^2 values for the first falling rate zone.

Drying Condition	Slope	$(D_{eff}/L^2)x10^5$ (sec^{-1})	r^2
Water treated			
40ºC	-0.0035	2.36	0.9993
50ºC	-0.0057	3.85	0.9999
60ºC	-0.0171	11.55	0.9984
70ºC	-0.0526	35.53	0.9956
1% ascorbic acid			
50ºC	-0.0059	3.99	0.9999
60ºC	-0.0105	7.09	0.9998
70ºC	-0.0160	10.81	0.9978
1% sodium bisulfite			
50ºC	-0.0067	4.53	0.9999
60ºC	-0.0144	9.73	0.9995
70ºC	-0.0091	6.15	0.9999
1% citric acid 50ºC	-0.0048	3.24	0.9999
2% ascorbic acid 60ºC	-0.0185	12.50	0.9997
2% sodium bisulfite 60ºC	-0.0160	10.81	0.9985
1% sodium bisulfite 15min. blanching 60ºC	-0.0154	10.40	0.9989

The plots and Table 3.1 indicates that with increasing temperature, regardless of pretreatment type drying rate and effective diffusivities increased except the case of sodium bisulfite (Figure 3.4), for which the effective diffusivity of 70ºC was smaller than that dried at 60ºC. This might be due to the greater penetration ability of sodium bisulfite into the food due to ionic dissociation compared to ascorbic acid which is also favored by higher temperature (Sapers, 1993). Due to this higher penetration, diffusion of water molecules from the interior of the food might have been hindered by the counter diffusing of sodium bisulfite molecules as well as narrowing and clogging of the pores by deposition of the solid due to evaporation.

In the falling rate period, it is reported that all mechanisms of internal mass transfer are affected by temperature while air flow rate is of minor significance (Karathanos and Belessiotis, 1997). In this study, air flow rate was kept constant and temperature was the major influencing factor for the effective diffusivities. However, pretreatments at high temperatures, especially at 70ºC, seemed to be effective on D_{eff}/L^2. The untreated sample had the highest D_{eff}/L^2 where the sodium bisulfite treated sample had the lowest D_{eff}/L^2. Therefore, in conjunction with the explanation above, it might be concluded that sodium bisulfite decreases drying rate at relatively high drying temperatures more than ascorbic acid. At 50ºC, ascorbic acid, sodium bisulfite and citric acid did not significantly affect the drying rate. At 60ºC, increasing the concentrations of sodium bisulfite and ascorbic acid and decreasing the blanching time had unclear effects and the deviations might be due to the different groups of artichokes (A,B, and C) used in the drying experiments. Therefore the groups were also compared. The initial percent moisture content data for the different artichoke groups are given in Appendix B Table B.1. Using the experimental data in Appendix C Tables C.5.1 to C.5.3, Figures 3.9 to 3.11 were plotted.

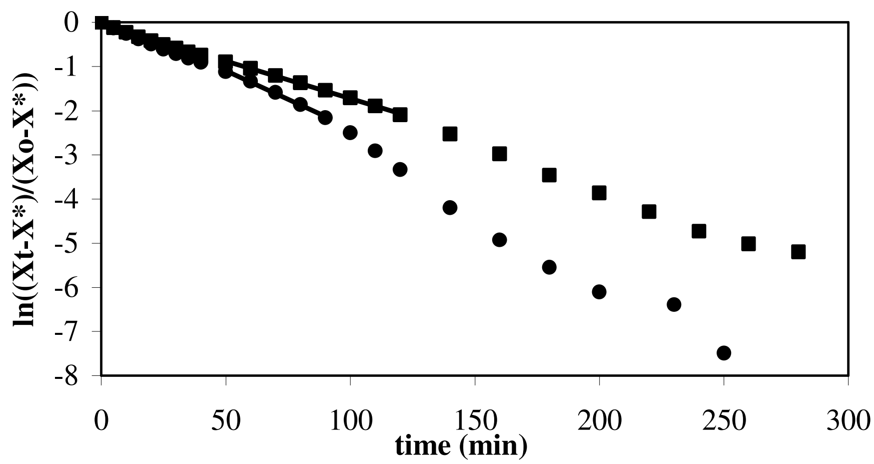


Figure 3.9 Variation of dimensionless moisture content with time for water treated samples dried at 60ºC for the groups A and B. (■) group B (●) group A

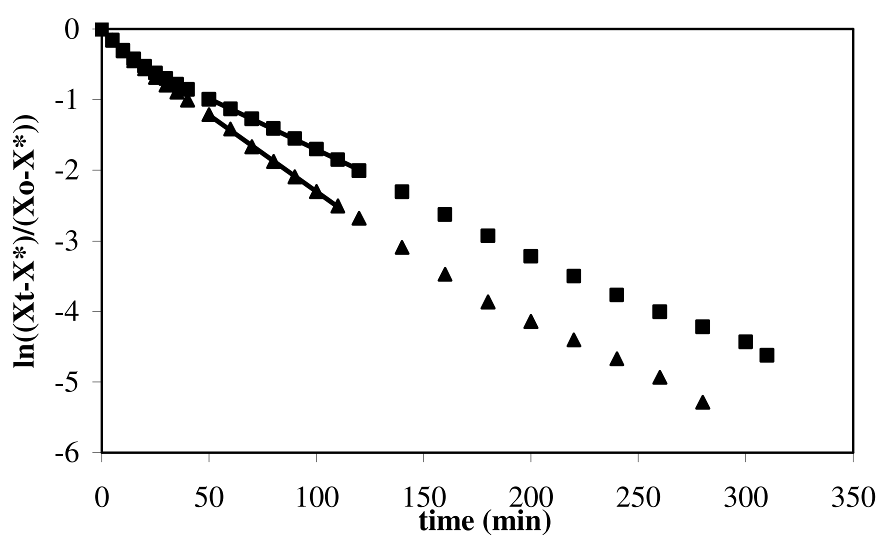
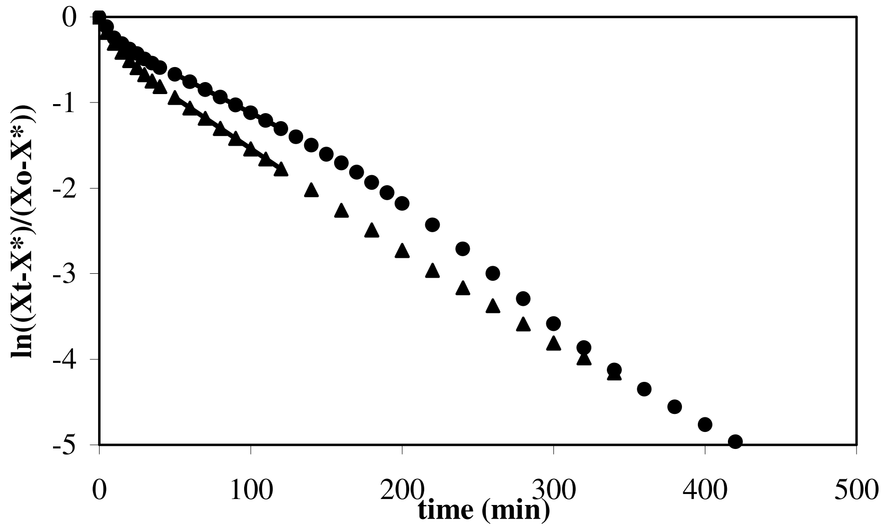


Figure 3.10 Variation of dimensionless moisture content with time for samples treated with 1% sodium bisulfite solution and dried at 60ºC for the groups B and C. (■) group B (▲) group C



C

Figure 3.11 Variation of dimensionless moisture content with time for samples treated with 1% sodium bisulfite solution and dried at 70ºC for the groups A and C. (●) group A (▲) group C

The calculated values of D_{eff}/L^2 for the different artichoke groups are tabulated in Table 3.2. It can be observed that the groups have slightly different D_{eff}/L^2 values. The minimum difference is between the groups A and C and the maximum is between the groups A and B. This maximum deviation can also be caused by the storage time of the artichoke used in this experiment since group A artichoke was stored for 2.5 months in order to see if time affected drying characteristics. It can be concluded that during storage, cell structure tended to have lower barrier to moisture diffusion. Those deviations between the groups might be the causes of slight differences in the calculated results between the samples. However, there might have been another fact affecting the results; the degree of manual cleaning and trimming process. In order to observe this, experiments with a deeply scraped and a half artichoke were performed and compared with the normal and whole, respectively. Using the data in Appendix C Table C 6.1 to 6.3 Figures 3.12 and 3.13 were plotted.

Table 3.2 D_{eff}/L^2 values for the different groups of artichokes.

Drying Condition	Groups	Slope	$(D_{eff}/L^2)x10^5$ (sec^{-1})	r^2
Water treated 60ºC	**Group A**	-0.0260	17.56	0.9961
	Group B	-0.0171	11.55	0.9984
1% sodium bisulfite 60ºC	**Group B**	-0.0144	9.73	0.9995
	Group C	-0.0217	14.66	0.9993
1% sodium bisulfite 70ºC	**Group A**	-0.0091	6.15	0.9999
	Group C	-0.0119	8.04	1.0000

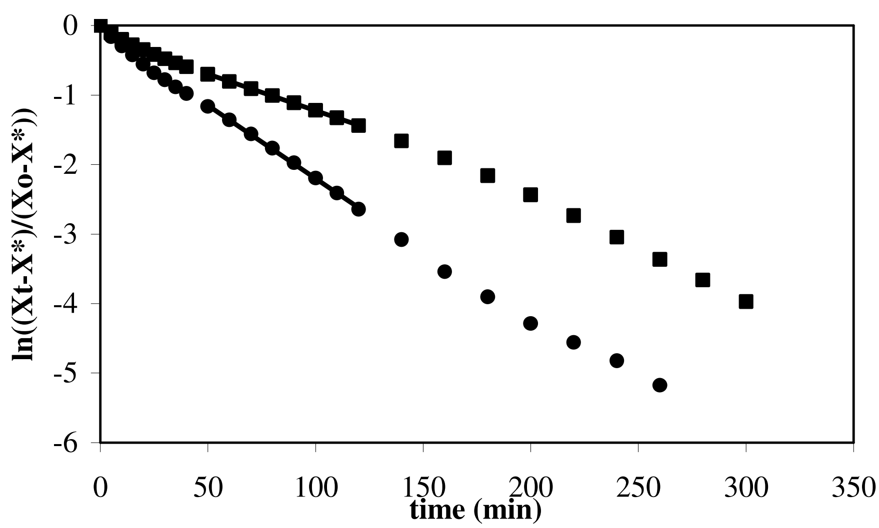


Figure 3.12 Variation of dimensionless moisture content with time for samples treated with 1% ascorbic acid solution and dried at 60ºC for the deeply scraped and the normal. (●) deeply scraped (■) normal

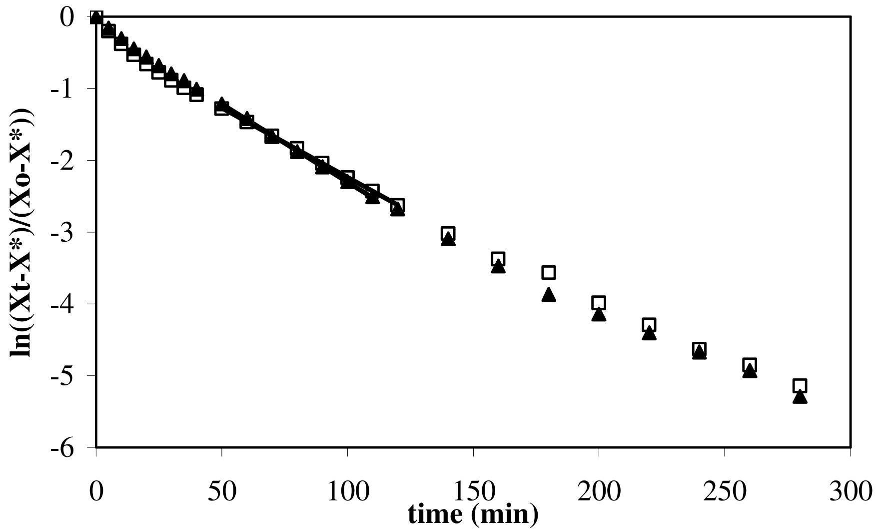


Figure 3.13 Variation of dimensionless moisture content with time for samples treated with 1% sodium bisulfite solution and dried at 60ºC for the half and the whole. (□) half (▲) whole

Using figures 3.12 and 3.13 Table 3.3 is prepared. From the analysis of the table and the figures, it can be concluded that drying rate is not significantly affected by halving the artichoke. This is because the diffusion greatly occurs normal to the cylindrical surface hence through the thickness which is also proved by the deeply scraped artichoke results. Thus, small deviations in the results might also have been due to the slightly different thicknesses of the artichoke samples.

Table 3.3 D_{eff}/L^2 values for deeply scraped and half artichokes.

Drying Condition	**Artichoke Heart**	**Slope**	**$(D_{eff}/L^2)x10^5$ (sec^{-1})**	**r^2**
1% ascorbic acid 60ºC	**Deeply scraped**	-0.0211	14.25	0.9993
	Normal	-0.0105	7.09	0.9998
1% sodium bisulfite 60ºC	**Half**	-0.0193	13.04	0.9998
	Whole	-0.0217	14.66	0.9993
1% sodium bisulfite	**1^{st} half, 60ºC**	-0.0193	13.04	0.9998
	2^{nd} half, 25ºC	-0.0015	1.01	0.9991

Table 3.3 also contains the same artichokes dried at different temperatures, 60 and 25ºC. The experiment was performed mainly to compare the effect of temperature on rehydration and color with the same artichoke.

3.1.2 Effect of Temperature

Using the temperatures and the corresponding D_{eff}/L^2 values for the water treated artichoke hearts (Table 3.4) and treating them according to Eq. 1.19 an Arrhenius type plot is shown in Figure 3.14.

Table 3.4 D_{eff}/L^2 values for water treated artichoke hearts.

T (ºC)	**1/T (1/K)**	**D_{eff}/L^2**	**ln (D_{eff}/L^2)**
40	0.00319	2.36	0.86
50	0.00310	3.85	1.35
60	0.00300	11.55	2.45
70	0.00292	35.53	3.57

D_0/L^2 and the activation energy were found from the intercept and the slope of the line as 9.36×10^{13} sec^{-1} and 82025.09 kj/kg mol, respectively. The activation energy is quite high when compared with other food materials. The difference might especially be due to the artichoke's structure and changes in its size and shape. Also, it might be because of the used diffusional zone as in this study only the first zone was taken. Although the samples were not treated with solutions, they were dipped into distilled water at their drying temperatures for 30 minutes. Therefore, higher temperatures might have resulted in higher effective diffusivities because of tissue softening within this dipping period. This also resulted in a greater slope thus, indicating higher activation energy than expected (15000-40000 kj/kg mol) (Lenz, 2003).

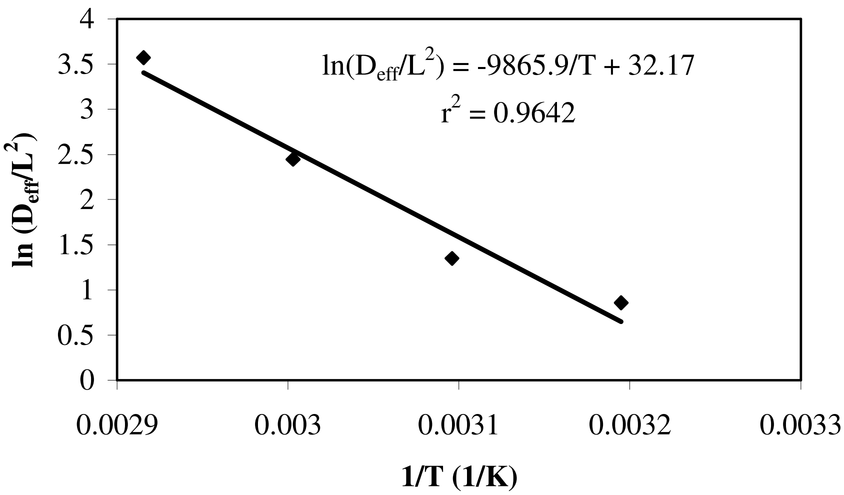


Figure 3.14 Arrhenius type plot for the water treated artichoke hearts.

3.2 Rehydration of Artichoke

Soaking is a long process in which the conditions affect cooking, nutritional and physical properties of end products. Therefore, soaking needs to be characterized for practical applications and time for soaking should be predictable since it is considered as a quality parameter for a dehydrated food. In the light of this, rehydration data were obtained as given in Appendix D Tables D.1.1 to D.4.4. Using Tables D.1.1 to D.1.4, water absorption kinetics of the dried artichokes for the water treated samples at the studied temperatures was plotted (Fig.3.15).

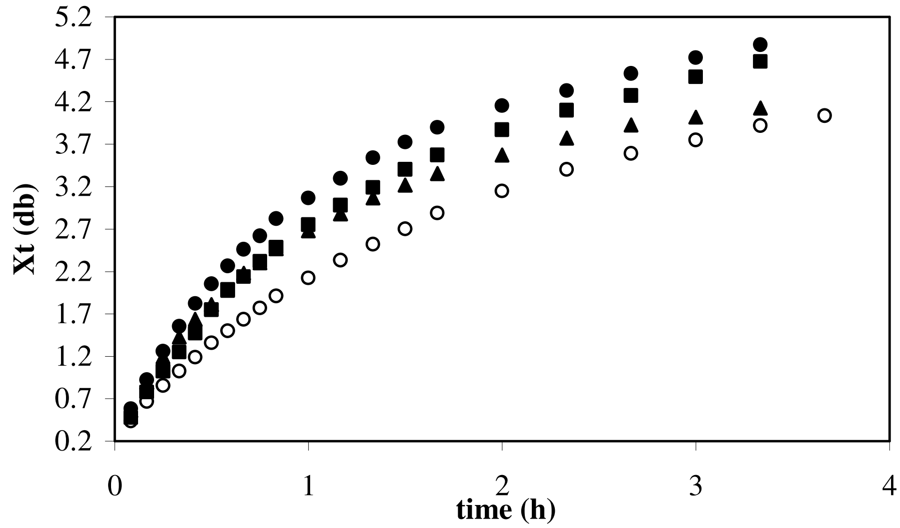


Figure 3.15 Rehydration at 20ºC of the water treated artichoke hearts dried at the studied temperatures. (○) 40ºC (▲) 50ºC (■) 60ºC (●) 70ºC

Figure 3.15 indicates that higher drying temperatures resulted in slightly higher water absorption capacities. This might be due to the structural damage within the artichoke tissues which was caused by moisture loss from the cells and shrinkage accordingly.

Also the curve points out that the dried artichoke hearts exhibited high water absorption in the initial stages whereas the absorption gradually decreased later. This is a typical behavior so by using Eq. 1.13 and the calculated data in Tables D.1.1 to D.4.4, the plots for rehydration of artichokes according to the Peleg model were prepared as given in Figures 3.16 to 3.22.

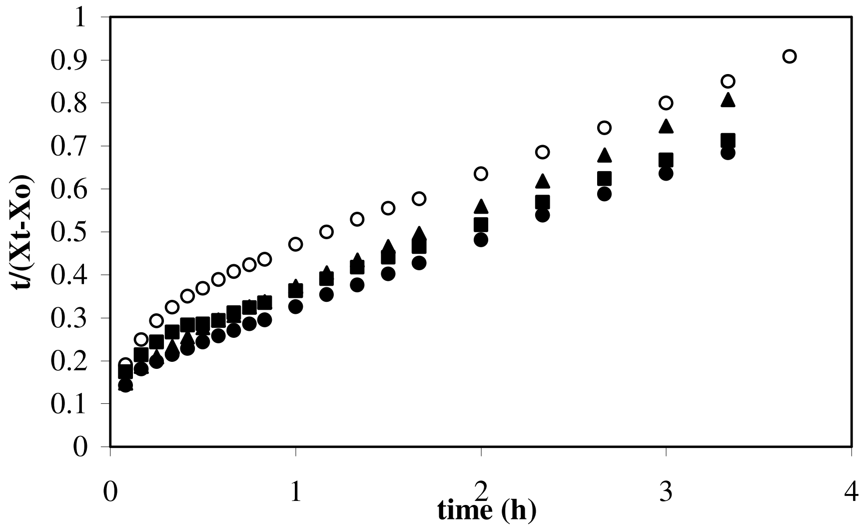


Figure 3.16 Application of Peleg model to rehydration at 20ºC of dried artichoke hearts pretreated with distilled water. (○) 40ºC (▲) 50ºC (■) 60ºC (●) 70ºC

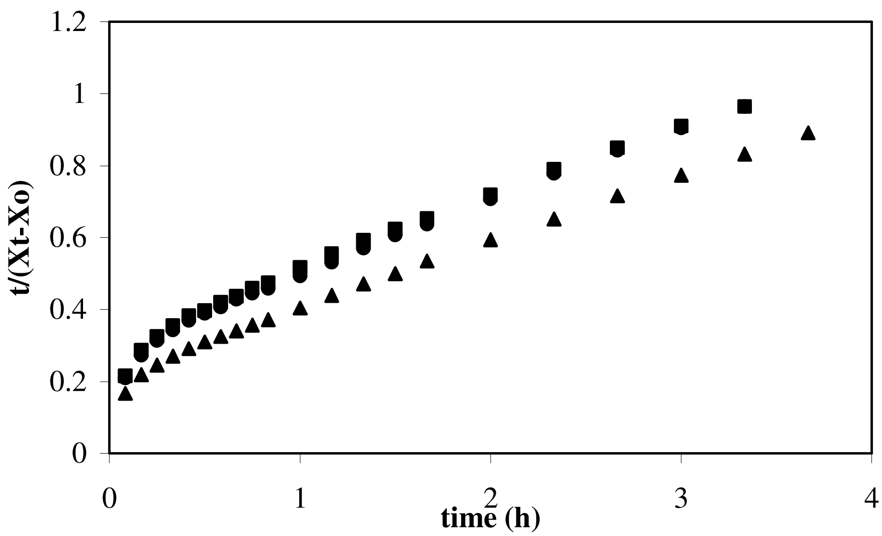


Figure 3.17 Application of Peleg model to rehydration at 20ºC of dried artichoke hearts pretreated with 1% ascorbic acid solution. (▲) 50ºC (■) 60ºC (●) 70ºC

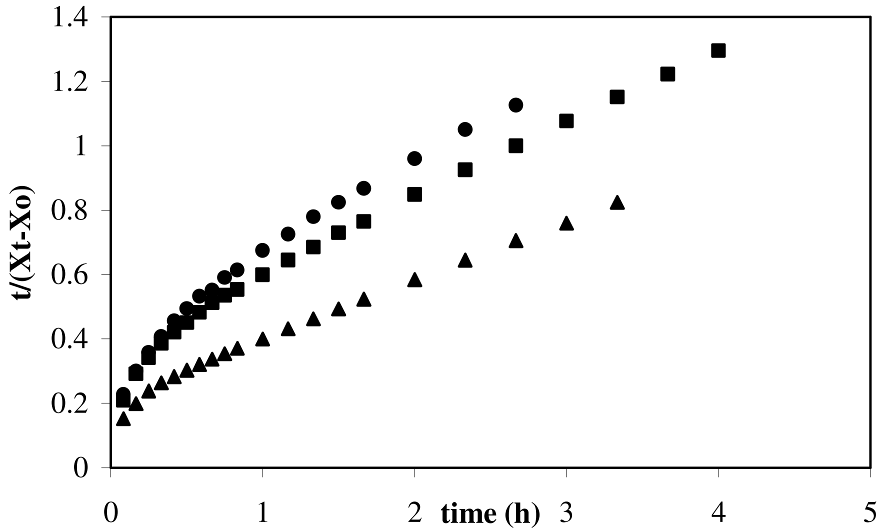


Figure 3.18 Application of Peleg model to rehydration at 20ºC of dried artichoke hearts pretreated with 1% sodium bisulfite solution. (▲) 50ºC (■) 60ºC (●) 70ºC

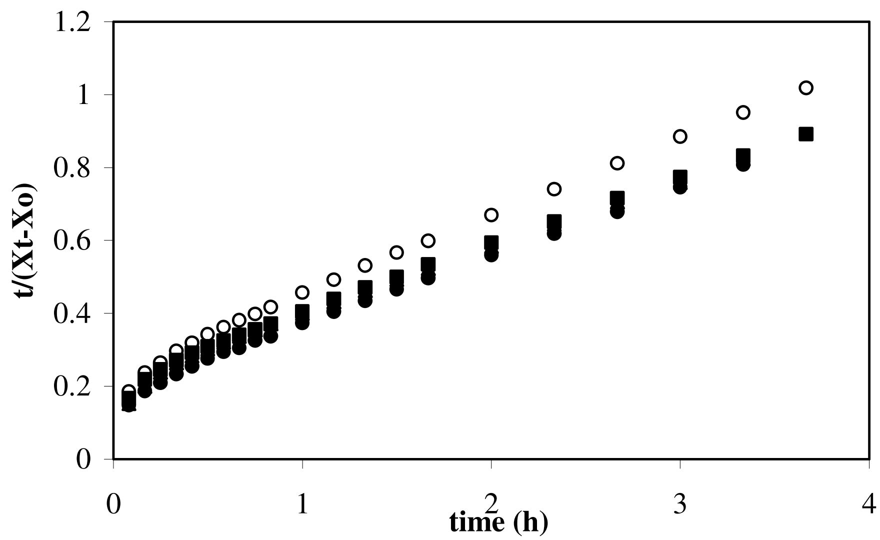


Figure 3.19 Application of Peleg model to rehydration at 20ºC of the artichoke hearts dried at 50ºC according to the different pretreatments.

(▲) 1% sodium bisulfite (■) 1% ascorbic acid (●) water treated (○) 1% citric acid

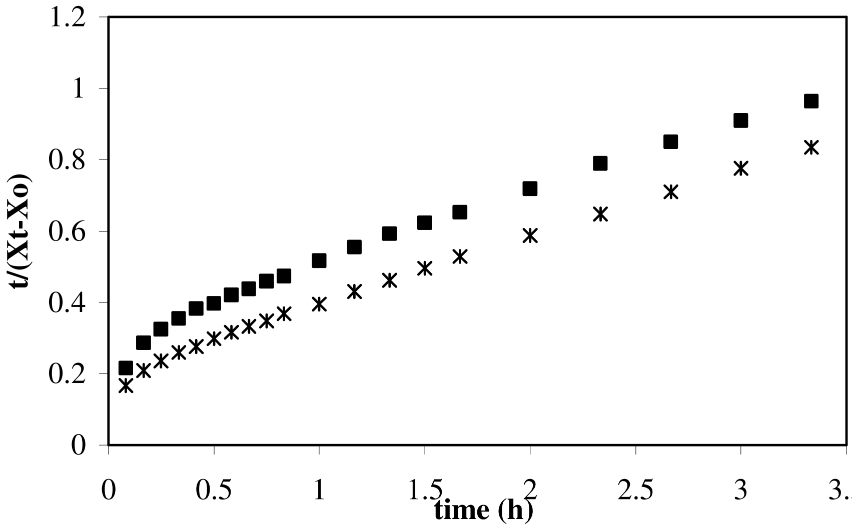


Figure 3.20 Application of Peleg model to rehydration at 20ºC of the artichoke hearts dried at 60ºC according to ascorbic acid concentration in pretreatment.
(■) 1% (*) 2%

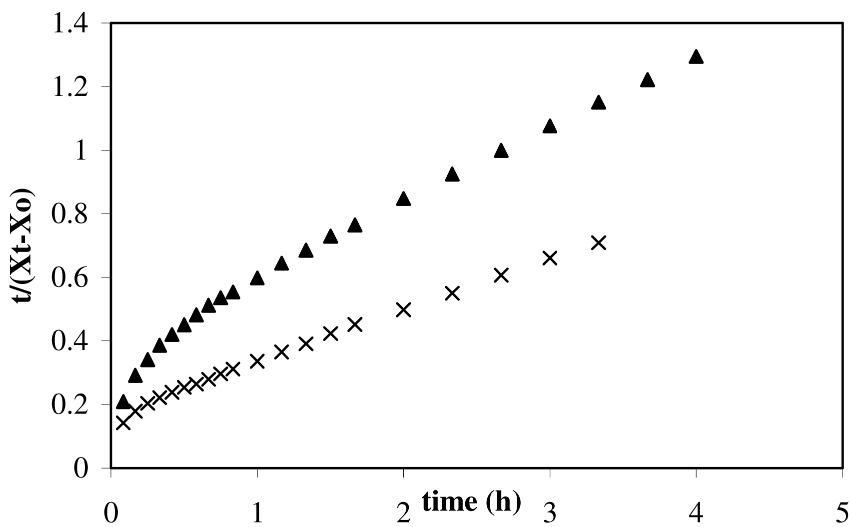


Figure 3.21 Application of Peleg model to rehydration at 20ºC of the artichoke hearts dried at 60ºC according to sodium bisulfite concentration in pretreatment.
(▲) 1% (x) 2%

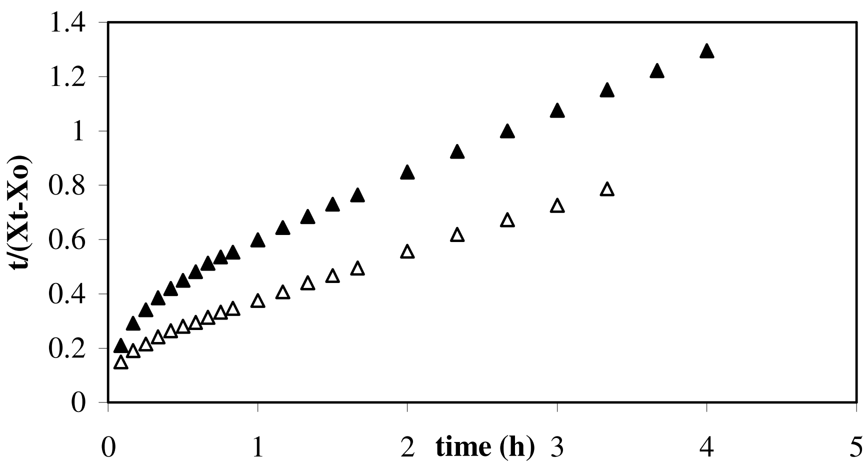


Figure 3.22 Application of Peleg model to rehydration at 20ºC of the artichoke hearts dried at 60ºC for 1% sodium bisulfite pretreatment according to treatment time. (▲) 30 minutes (Δ) 15minutes

Figures 3.16 to 3.18 show the effect of the drying temperature on the degree of rehydration. In the case of water treated artichokes (Fig. 3.16) it can be visually observed that a slight increase occurred when drying temperature increased. This might be due to formation of cracks occurred by higher drying temperatures where the cracks provided the diffusion of water inside the tissues easily. However, inspection of Figures 3.17 and 3.18 showed that pretreatments at higher temperatures decreased rehydration capacity. This might again be due to the partial clogging of the pores within the artichokes by the solid deposited and its increased penetration with high temperature.

Figures 3.19 to 3.22 are for additional comparison on the basis of the selected parameters. Figure 3.19, which is for drying at 50ºC for the pretreatments used and is in accordance with the discussion above since it was a relatively low temperature. Figures 3.20 and 3.21 show that increasing the concentration did not decrease the rehydration capacity for artichokes dried at 60ºC. Further, from Figure 3.22 it can be seen that decreasing the blanching time increased rehydration capacity for 1%

sodium bisulfite solution treated artichokes dried at 60ºC since clogging of the pores with the solid decreased with a decrease in dipping time.

As a quantitative aid to the comparison the Peleg constants were calculated from the slopes and the intercepts of the lines and tabulated in Table 3.5.

Table 3.5 Values of the Peleg constants for rehydration at 20ºC.

Drying Condition	k_2 (slope) $(\text{mc db})^{-1}$	k_1 (intercept) (h/mc db)	r^2
Water treated			
40ºC	0.1813	0.2650	0.9807
50ºC	0.1939	0.1697	0.9962
60ºC	0.1568	0.2023	0.9941
70ºC	0.1605	0.1594	0.9973
1% ascorbic acid			
50ºC	0.1914	0.2048	0.9949
60ºC	0.2153	0.2817	0.9852
70ºC	0.2174	0.2668	0.9892
1% sodium bisulfite			
50ºC	0.1928	0.1956	0.9909
60ºC	0.2569	0.3109	0.9843
70ºC	0.3316	0.3049	0.9734
1% citric acid 50ºC	0.2220	0.2218	0.9956
2% ascorbic acid 60ºC	0.1963	0.1928	0.9956
2% sodium bisulfite 60ºC	0.1670	0.1638	0.9959
1% sodium bisulfite 15min. blanching 60ºC	0.1867	0.1793	0.9937

All of the rehydration experiments were performed at 20ºC. Therefore, Peleg constants were not analyzed according to temperature. However, it is well known that k_1 is inversely affected by rehydration temperature whereas k_2 is mostly considered independent.

According to Table 3.5, the initial absorption rate ($1/ k_1$) values appeared to be in the range 3.22-6.27 where again the effects of solid deposition and high drying temperature seem to be valid.

The capacity constant k_2 indicates that the moisture uptake is nearly the same for all the 50ºC dried samples whereas it shows a decrease with pretreatment at 60 and 70ºC. Uptake capacity is mainly dependent on the food itself as well as the drying condition which can be seen from the results also. Variation of k_2 with the drying temperature was not very clear for the water treated samples. With the other pretreated samples, there was a slight increase with the ascorbic acid treated ones and also a higher increase with sodium bisulfite treated samples. These findings again verify the solid deposition which decreased the absorption capacity. Further, the effect is more pronounced with sodium bisulfite pretreatment due to its higher penetration rate than ascorbic acid (Sapers, 1993).

The maximum rehydration capacities could also be calculated by taking the inverse of k_2 and the calculated results could be compared with the experimental ones since Peleg Equation was designed for predicting long range moisture absorption from experimental data obtained over a short time. Therefore, in some rehydration experiments, the samples were kept in distilled water for 24 hours in order to compare. The results are tabulated in Table 3.6. It can be concluded that Peleg equation was appropriate for rehydration of dried artichoke hearts since the experimental and the calculated data were almost close to each other.

Table 3.6 Experimental and calculated data for the maximum rehydration capacities based on the average initial moisture contents.

Pretreatment and Drying Condition	Experimental Data (w/w) (mc-db)	Calculated Value (w/w) (mc-db)	% Rehydration
1% ascorbic acid 60ºC drying	4.54	4.64	89.37
1% ascorbic acid 70ºC drying	5.06	4.60	62.32
1% sodium bisulfite 60ºC drying	3.65	3.89	71.85
1% sodium bisulfite 70ºC drying	3.92	3.02	48.28
1% sodium bisulfite (15 min blanching) 60ºC drying	4.73	5.36	135.14
1% sodium bisulfite 70ºC drying Group C	3.96	3.69	113.14

Some differences between the rehydration results might also have been due to the group differences and manual processing. Using Appendix D Tables D.5.1 to D.5.3 and Tables D.6.1 to D.6.3 Figures 3.23 to 3.28 were plotted and Tables 3.7 and 3.8 were prepared.

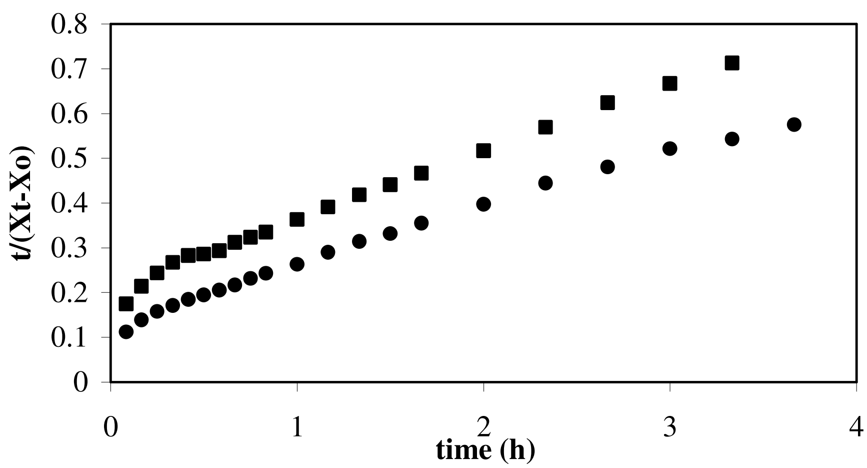


Figure 3.23 Application of Peleg model to rehydration at 20ºC for water treated artichoke hearts dried at 60ºC for the groups A and B. (■) group B (●) group A

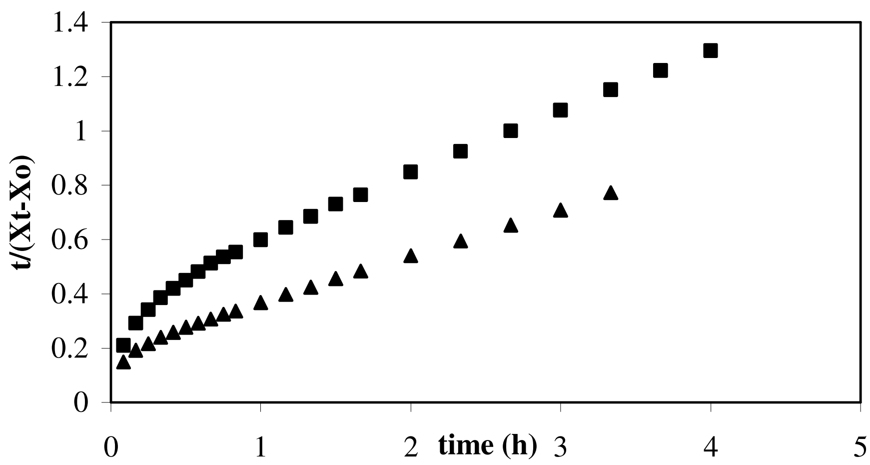


Figure 3.24 Application of Peleg model to rehydration at 20ºC for 1% sodium bisulfite treated artichoke hearts dried at 60ºC for the groups B and C.
(■) group B (▲) group C

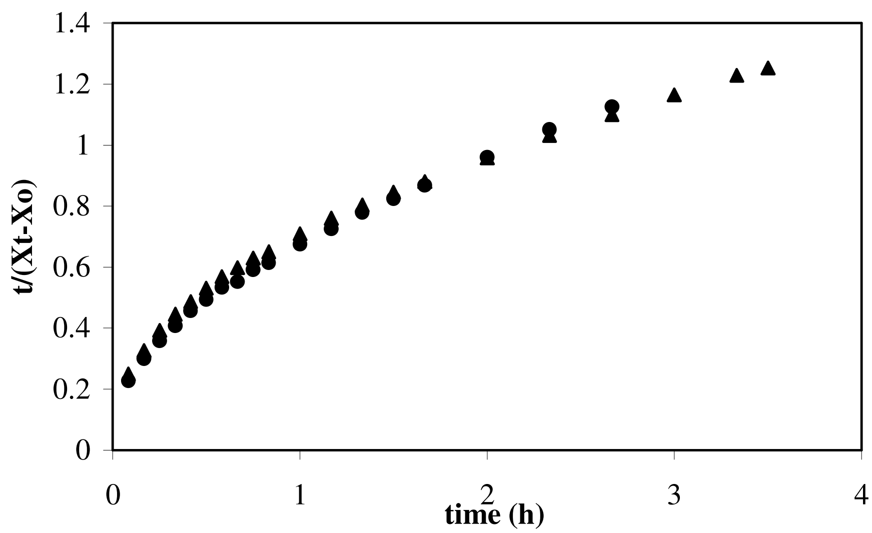


Figure 3.25 Application of Peleg model to rehydration at 20ºC for 1% sodium bisulfite treated artichoke hearts dried at 70ºC for the groups A and C.
(●) group A (▲) group C

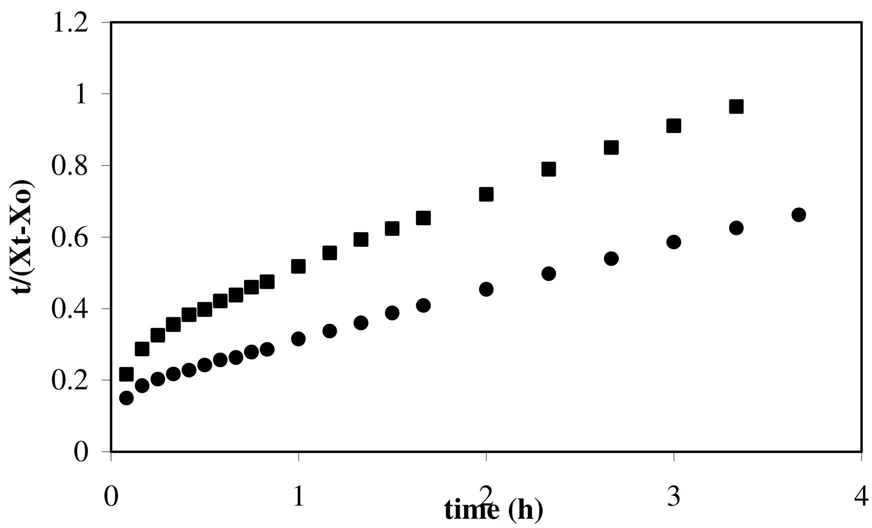


Figure 3.26 Application of Peleg model to rehydration at 20ºC for 1% ascorbic acid treated artichoke hearts dried at 60ºC for the deeply and the normal scraped. (●) deeply scraped (■) normal

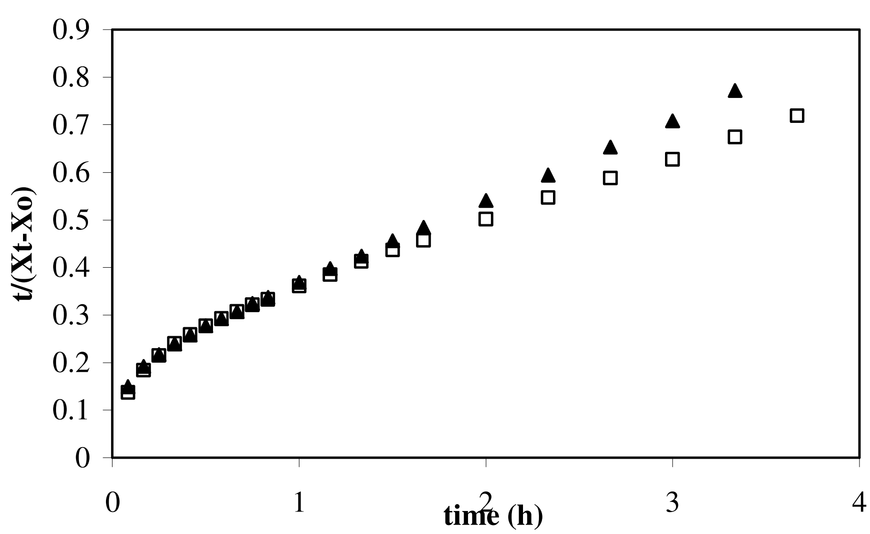


Figure 3.27 Application of Peleg model to rehydration at 20ºC for 1% ascorbic acid treated artichoke hearts dried at 60ºC for the half and the whole. (□) half (▲) whole

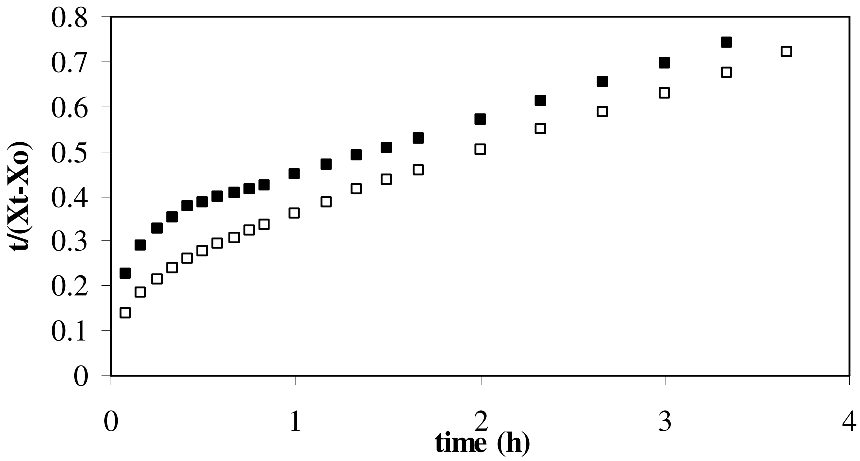


Figure 3.28 Application of Peleg model to rehydration at 20ºC for 1% sodium bisulfite treated artichoke heart for two halves dried at two temperatures.
(□) 1st half, dried at 60ºC (■) 2nd half, dried at 25ºC

Table 3.7 Values of the Peleg constants for different groups of artichokes.

Drying Condition	Groups	k_2 (slope) $(mc\ db)^{-1}$	k_1 (intercept) (h/mc db)	r^2
Water treated 60ºC	**Group A**	0.1286	0.1305	0.9928
	Group B	0.1568	0.2023	0.9941
1% sodium bisulfite 60ºC	**Group B**	0.2569	0.3109	0.9843
	Group C	0.1802	0.1781	0.9946
1% sodium bisulfite 70ºC	**Group A**	0.3316	0.3049	0.9734
	Group C	0.2711	0.3811	0.9595

Table 3.8 Values of the Peleg constants for deeply scraped and half artichokes.

Drying Condition	Artichoke Heart	k_2 (slope) $(mc\ db)^{-1}$	k_1 (intercept) (h/mc db)	r^2
1% ascorbic acid 60ºC	**Deeply scraped**	0.1385	0.1694	0.9963
	Normal	0.2153	0.2817	0.9852
1% sodium bisulfite 60ºC	**Half**	0.1492	0.1934	0.9820
	Whole	0.1802	0.1781	0.9946
1% sodium bisulfite	**1st half, 60ºC**	0.1492	0.1934	0.9820
	2nd half, 25ºC	0.1363	0.2984	0.9678

Inspection of the figures and the tables reflect a slight difference between the groups. Since k_2 was dependent on the food itself, the compositional variations between groups resulted in changes in k_2 values. Group C seemed to have maximum absorption capacity whereas group B had the minimum. Initial rate of absorption was defined by the reciprocal of k_1 which was mainly dependent on temperature, had unclear changes. Since the experiments were performed isothermally, the deviations might have appeared because of structural and compositional changes within the groups. Therefore, it can be claimed that harvesting time and post harvest storage conditions seemed to have a slightly positive effect on the rehydration capacity.

The degree of scraping of artichoke according to rehydration revealed that thickness is an important parameter in rehydration since diffusional moisture absorption was mostly affected by thickness, whereas cutting the artichoke into two pieces did not affect rehydration capacity as much as thickness. On the other hand, when two halves of the same artichoke treated at 60ºC with 1% sodium bisulfite solution but one dried at about room temperature as an extreme and the other at 60ºC indicated a slight unfavorable effect of high temperature on the rehydration capacity despite a higher initial rate.

3.3 Color of Artichoke

Color is one of the quality attributes for dried products since it is the most important factor for consumer acceptance. The data for the fresh and the rehydrated samples taken from the total surface area of the internal and external parts of the artichoke hearts were converted into ΔL, ΔE and ΔBI values in order to compare discoloration. All of the relevant data are given in Appendix E Tables E.1.1 to E.4.5.

ΔL and ΔE values can be analyzed together since discoloration mostly occurred in the lightness index of the artichokes, which is taken as a measurement of browning (Maskan, 2001). However, ΔBI values were not correlated with these. This might be due to other color indices since redness (a) and yellowness (b) were also dominant for browning index. For ΔBI analysis it has been stated that if $\Delta BI<0$

enzymatic or nonenzymatic reactions did not occur (Palou at al, 1999). The BI values represent the pure brown color therefore it is more appropriate to compare them for pure brown discolored food, esp. bananas. However, the values of ΔBI reflected and suited with the expectations since sodium bisulfite treated samples mostly had negative values whereas the other treatments had positive values. This indicated that sodium bisulfite was the best among used chemical treatments for prevention of discoloration.

In the case of ΔL and ΔE, more detailed analysis was appropriate. Comparison of sodium bisulfite on the basis of drying temperature indicated that discoloration was not seriously affected by temperature. Nevertheless, the best result was obtained with 50ºC dried sample. The deviations might have occurred because of the differences between the amounts of disrupted cells since it fastened the discoloration reactions. Ascorbic acid was not as effective as sodium bisulfite. This is expected since sodium bisulfite is stated to have better penetration and greater stability than ascorbic acid (Sapers, 1993). The best result for ascorbic acid was for the 70ºC dried sample, which reflected the fact that high temperature blanching increased penetration of ascorbic acid into the tissues. Maximum discoloration occurred in 60ºC unexpectedly which can be explained by compositional differences between artichokes. Within the water treated samples the highest discoloration occurred in 40ºC dried sample. This was also the most discolored one among all the samples indicating that drying was slow and time was long enough for the browning reactions in addition to relatively low blanching temperature to inactivate the enzymes.

Citric acid was also compared with ascorbic acid using 50ºC as the drying temperature. The results were almost identical. On the other hand, increasing the concentration of ascorbic acid solution from 1 % to 2% resulted in a decrease in discoloration as expected. However, increase in the concentration of sodium bisulfite did not affect discoloration much, where a slight decrease observed might be due to the differences between the artichokes. Lowering the blanching time from 30 minutes to 15 minutes for sodium bisulfite treated and 60ºC dried samples resulted in more discoloration most probably due to less penetration of the chemical into the tissues.

There was also a need for group analysis since fresh color data could only be obtained via cutting the brown surface layer due to fast discoloration reactions. The analysis of different groups at first revealed that group B was the most stable one among the others however, within the same groups, stability to discoloration was also unclear since it was mainly dependent on the presence and the amount of polyphenol oxidases and phenolic compounds.

Different manual processing revealed that deeply scraped artichoke was more stable to discoloration since penetration was higher. Half artichoke had about the same color with the whole.

The results pertaining to the two halves of the same artichoke treated at 60ºC with 1% sodium bisulfite and one dried at 60ºC and the other at 25ºC was the most clear one to see the effect of drying temperature on discoloration. With regard to color at 25ºC discoloration was slightly higher. The reason might principally be due to availability of sufficient time for reactions to take place until drying since polyphenol oxidase, which is destructed at the range 70-90ºC (McCord and Kilara, 1983), was stable to heat treatment (blanching at 60ºC).

Within all the results, the best color was obtained for the sample dried at 50ºC which was treated with 1% sodium bisulfite whereas the worst color was obtained with the water treated sample dried at 40ºC.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

In this study, it was aimed to investigate the effects of pretreatment and air temperature on the drying characteristics, rehydration quality and color of artichoke hearts under constant external drying conditions. In the light of the experimental results and the related discussion the following conclusions can be drawn.

Air drying rate of artichoke is controlled mainly by internal moisture diffusion in which the effective diffusion coefficient shows an Arrhenius type of dependence on temperature. Rehydration of dried artichokes can be explained by Peleg equation.

Increasing the drying temperature resulted in an increase in the drying rate, effective moisture diffusivity and a slight increase in rehydration capacity for water treated samples. However, for the 1% sodium bisulfite treated samples, relatively high temperature resulted in a decrease in drying rate, effective diffusivity and rehydration capacity. This indicates that high penetration of the solids into the food is not very desirable as the solids deposit and clog the pores.

Decreasing the thickness by deeply scraping the artichoke heart seems beneficial for increasing drying rate, effective diffusivity and rehydration capacity. Increasing the concentrations of the solutions and decreasing the blanching time for

60ºC drying seemed to increase the effective diffusivities however both positive and negative deviations in the quality attributes are to be expected because of the differences between artichoke groups. Artichokes, within the same group and among three different groups (A, B and C) had different drying, rehydration and color properties which reflected the possibility of deviations. These indicate that for an acceptable product rapid processing with suitable post harvest storage and sufficient degree of scraping must be practiced.

Color, which is the mostly sought quality parameter for consumer acceptance, was best protected by sodium bisulfite pretreatment and by drying at about 50ºC where water treatment at relatively low temperature of 40ºC is not at all recommendable. Use of citric acid or ascorbic acid solution for pretreatment practically has no difference. Increasing the concentration of ascorbic acid solution gives a better color which is not valid for sodium bisulfite solution where in all cases sufficient blanching time should be used to minimize discoloration.

Fresh artichokes dried at 50ºC and pretreated with 1% sodium bisulfite solution for 30 minutes with sufficient degree of scraping seem to be a considerable product according to the studied quality parameters.

4.2 Recommendations

This study can be considered to be preliminary for dehydration of artichoke hearts since there is no other study on drying of artichoke in the literature. For the future studies, instead of sodium bisulfite, combinations of ascorbic and citric acid can be used. Other blanching time and temperature combinations as well as nutritional and textural changes can be studied. Rehydration water can be analyzed for nutrient and color losses. Economical and nutritional comparison between dried and canned artichokes can be studied. In order to prevent deviations within the artichokes, precaution must be taken. At least dividing the sample into two will be a feasible solution for determination of the initial color (which can be measured via cutting since browning occurs too fast) precisely.

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APPENDIX A

TABLES RELATED TO ARTICHOKE (*Cynara scolymus* L.)

Table A.1 Composition of artichoke (Anonymous. 2004a).

Nutrient	Units	Value per 100 grams of edible portion
Proximates		
Water	g	84.94
Energy	kcal	47
Energy	kj	196
Protein	g	3.27
Total lipid (fat)	g	0.15
Ash	g	1.13
Carbohydrate, by difference	g	10.51
Fiber, total dietary	g	5.4
Minerals		
Calcium, Ca	mg	44
Iron, Fe	mg	1.28
Magnesium, Mg	mg	60
Phosphorus, P	mg	90
Potassium, K	mg	370
Sodium, Na	mg	94
Zinc, Zn	mg	0.49
Copper, Cu	mg	0.231
Manganese, Mn	mg	0.256
Selenium, Se	μg	2

Table A.1 (continued)

Vitamins		
Vitamin C, total ascorbic acid	mg	11.7
Thiamin	mg	0.072
Riboflavin	mg	0.066
Niacin	mg	1.046
Pantothenic acid	mg	0.338
Vitamin B-6	mg	0.116
Folate, total	µg	680
Folic acid	µg	0
Folate, food	µg	680
Folate, DFE	µg_DFE	680
Vitamin B-12	µg	0.00
Vitamin A, IU	IU	0
Vitamin A, RAE	µg_RAE	0
Retinol	µg	0
Vitamin K (phylloquinone)	µg	140.0
Lipids		
Fatty acids, total saturated	g	0.035
4:0	g	0.000
6:0	g	0.000
8:0	g	0.000
10:0	g	0.000
12:0	g	0.002
14:0	g	0.002
16:0	g	0.029
18:0	g	0.003
Fatty acids, total monounsaturated	g	0.005
16:1 undifferentiated	g	0.000
18:1 undifferentiated	g	0.005
20:1	g	0.000
22:1 undifferentiated	g	0.000
Fatty acids, total polyunsaturated	g	0.063
18:2 undifferentiated	g	0.046
18:3 undifferentiated	g	0.017
18:4	g	0.000
20:4 undifferentiated	g	0.000
20:5 n-3	g	0.000
22:5 n-3	g	0.000
22:6 n-3	g	0.000
Cholesterol	mg	0
Other		
Alcohol, ethyl	g	0.0

APPENDIX B

MOISTURE CONTENT AND PSYCHROMETRIC DATA

Table B.1 Initial moisture contents (average of the triplicates) of the artichoke groups and the standard deviations (AOAC, 930.04, 1995).

Artichoke Groups	%Moisture Content (wb)	(w/w) Moisture Content (db)
Group A	88.61 ± 2.56	8.12 ± 2.30
Group B	83.30 ± 2.39	5.08 ± 0.94
Group C	77.68 ± 1.80	3.50 ± 0.38
Average	83.20 ± 5.47	5.57 ± 2.35

Table B.2 Psychrometric data for the air at the surroundings.

Temperature dry bulb (°C)	Temperature wet bulb (°C)	% Relative humidity	Humidity (kg water vapor/kg dry air)
27	16	30	0.007

Table B.3 Psychrometric data for the air at the drying chamber.

Temperature dry bulb (°C)	Temperature wet bulb (°C)	% Relative humidity	Humidity (kg water vapor/kg dry air)
40	19	10	0.005
50	23	6	0.006
60	25	3.5	0.006
70	28	2.4	0.007

APPENDIX C

EXPERIMENTAL AND CALCULATED DATA FOR AIR DRYING OF ARTICHOKE HEARTS

Table C.1.1[*] Drying data for "water treated" artichoke hearts. $T_{db} = 40ºC$. $T_{wb} = 19ºC$.

time (min)	weight (g)	$(X_t\text{-}X^*)/(X_0\text{-}X^*)$	$\ln((X_t\text{-}X^*)/(X_0\text{-}X^*))$
0	23.93	1.000000	0.00000
5	22.27	0.920612	-0.08272
10	21.45	0.881396	-0.12625
15	20.84	0.852224	-0.15991
20	20.33	0.827834	-0.18894
25	19.87	0.805835	-0.21588
30	19.48	0.787183	-0.23929
35	19.10	0.769010	-0.26265
40	18.73	0.751315	-0.28593
50	18.12	0.722143	-0.32553
60	17.54	0.694405	-0.36470
70	17.01	0.669058	-0.40188
80	16.52	0.645624	-0.43754
90	16.05	0.623147	-0.47297
100	15.63	0.603061	-0.50574
110	15.21	0.582975	-0.53961
120	14.80	0.563367	-0.57382
140	14.08	0.528934	-0.63689
160	13.35	0.494022	-0.70518
180	12.70	0.462936	-0.77017
200	12.09	0.433764	-0.83526
220	11.52	0.406504	-0.90016
240	10.97	0.380201	-0.96706
270	10.16	0.341463	-1.07451
300	9.42	0.306074	-1.18393
330	8.73	0.273075	-1.29801
360	8.07	0.241511	-1.42084
390	7.48	0.213295	-1.54508
420	6.94	0.187470	-1.67414
450	6.46	0.164515	-1.80476
480	6.00	0.142516	-1.94830
510	5.62	0.124342	-2.08472
530	5.39	0.113343	-2.17734
at equilibrium	3.02		

* Group A

Table C.1.2*Drying data for “water treated” artichoke hearts. T_{db} = 50ºC. T_{wb} = 23ºC.

time (min)	**weight (g)**	**$(X_t-X^*)/(X_0-X^*)$**	**$\ln((X_t-X^*)/(X_0-X^*))$**
0	18.90	1.000000	0.00000
5	16.75	0.873455	-0.13530
10	15.59	0.805180	-0.21669
15	14.83	0.760447	-0.27385
20	14.22	0.724544	-0.32221
25	13.67	0.692172	-0.36792
30	13.19	0.663920	-0.40959
35	12.80	0.640965	-0.44478
40	12.45	0.620365	-0.47745
50	11.80	0.582107	-0.54110
60	11.23	0.548558	-0.60046
70	10.72	0.518540	-0.65674
80	10.24	0.490288	-0.71276
90	9.77	0.462625	-0.77084
100	9.32	0.436139	-0.82979
110	8.93	0.413184	-0.88386
120	8.55	0.390818	-0.93951
140	7.83	0.348440	-1.05429
160	7.24	0.313714	-1.15927
180	6.70	0.281931	-1.26609
200	6.22	0.253679	-1.37169
220	5.77	0.227192	-1.48196
240	5.33	0.201295	-1.60298
260	4.90	0.175986	-1.73735
280	4.54	0.154797	-1.86564
300	4.17	0.133019	-2.01726
320	3.84	0.113596	-2.17510
340	3.52	0.094762	-2.35639
360	3.22	0.077104	-2.56260
380	2.96	0.061801	-2.78383
400	2.72	0.047675	-3.04335
420	2.51	0.035315	-3.34345
440	2.32	0.024132	-3.72422
at equilibrium	1.91		

* Group A

Table C.1.3* Drying data for "water treated" artichoke hearts. $T_{db} = 60°C$. $T_{wb} = 25°C$.

time (min)	**weight (g)**	**$(X_t$-$X^*)/(X_0$-$X^*)$**	**$\ln((X_t$-$X^*)/(X_0$-$X^*))$**
0	20.36	1.000000	0.00000
5	18.28	0.885210	-0.12193
10	16.72	0.799117	-0.22425
15	15.34	0.722958	-0.32440
20	14.17	0.658389	-0.41796
25	13.19	0.604305	-0.50368
30	12.34	0.557395	-0.58448
35	11.54	0.513245	-0.66700
40	10.87	0.476269	-0.74177
50	9.66	0.409492	-0.89284
60	8.61	0.351545	-1.04542
70	7.66	0.299117	-1.20692
80	6.86	0.254967	-1.36662
90	6.13	0.214680	-1.53861
100	5.51	0.180464	-1.71223
110	4.96	0.150110	-1.89638
120	4.47	0.123068	-2.09501
140	3.69	0.080022	-2.52545
160	3.16	0.050773	-2.98040
180	2.81	0.031457	-3.45914
200	2.62	0.020971	-3.86460
220	2.49	0.013797	-4.28331
240	2.40	0.008830	-4.72960
260	2.36	0.006623	-5.01728
280	2.34	0.005519	-5.19960
at equilibrium	2.24		

* Group B

Table C.1.4[*] Drying data for "water treated" artichoke hearts. T_{db} = 70ºC. T_{wb} = 28ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	22.09	1.000000	0.00000
5	18.15	0.802901	-0.21952
10	16.04	0.697349	-0.36047
15	14.39	0.614807	-0.48645
20	12.95	0.542771	-0.61107
25	11.68	0.479240	-0.73555
30	10.64	0.427214	-0.85047
35	9.62	0.376188	-0.97767
40	8.83	0.336668	-1.08866
50	7.44	0.267134	-1.32001
60	6.25	0.207604	-1.57212
70	5.04	0.147074	-1.91682
80	4.11	0.100550	-2.29710
90	3.36	0.063032	-2.76412
100	2.85	0.037519	-3.28291
110	2.49	0.019510	-3.93684
120	2.36	0.013007	-4.34231
140	2.23	0.006503	-5.03545
160	2.16	0.003002	-5.80864
180	2.14	0.002001	-6.21411
200	2.12	0.001001	-6.90726
220	2.10	0.000000	
240	2.10	0.000000	

* Group A

Table C.2.1* Drying data for "1% (w/v) ascorbic acid treated" artichoke hearts.

T_{db} = 50ºC. T_{wb} = 23ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	17.89	1.000000	0.00000
5	16.09	0.884615	-0.12260
10	14.80	0.801923	-0.22074
15	13.71	0.732051	-0.3119
20	12.87	0.678205	-0.38831
25	12.25	0.638462	-0.44869
30	11.78	0.608333	-0.49703
35	11.38	0.582692	-0.54010
40	11.01	0.558974	-0.58165
50	10.44	0.522436	-0.64925
60	9.96	0.491667	-0.70995
70	9.51	0.462821	-0.77042
80	9.11	0.437179	-0.82741
90	8.72	0.412179	-0.88630
100	8.35	0.388462	-0.94556
110	7.99	0.365385	-1.00680
120	7.66	0.344231	-1.06644
140	7.04	0.304487	-1.18913
160	6.48	0.268590	-1.31457
180	5.97	0.235897	-1.44436
200	5.49	0.205128	-1.58412
220	5.06	0.177564	-1.72842
240	4.68	0.153205	-1.87598
260	4.34	0.131410	-2.02943
280	4.02	0.110897	-2.19915
300	3.77	0.094872	-2.35523
320	3.53	0.079487	-2.53216
340	3.33	0.066667	-2.70805
360	3.17	0.056410	-2.87510
380	3.01	0.046154	-3.07577
at equilibrium	2.29		

* Group B

Table C.2.2* Drying data for "1% (w/v) ascorbic acid treated" artichoke hearts.

T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	22.21	1.000000	0.00000
5	20.16	0.892614	-0.11360
10	18.69	0.815610	-0.20382
15	17.54	0.755369	-0.28055
20	16.56	0.704034	-0.35093
25	15.70	0.658984	-0.41706
30	14.94	0.619172	-0.47937
35	14.25	0.583028	-0.53952
40	13.64	0.551074	-0.59589
50	12.59	0.496071	-0.70104
60	11.65	0.446831	-0.80558
70	10.81	0.402829	-0.90924
80	10.07	0.364065	-1.01042
90	9.38	0.327920	-1.11498
100	8.74	0.294395	-1.22283
110	8.18	0.265060	-1.32780
120	7.64	0.236773	-1.44065
140	6.74	0.189628	-1.66269
160	5.96	0.148769	-1.90536
180	5.32	0.115244	-2.16071
200	4.79	0.087480	-2.43634
220	4.36	0.064955	-2.73405
240	4.03	0.047669	-3.04348
260	3.78	0.034573	-3.36468
280	3.61	0.025668	-3.66251
300	3.48	0.018858	-3.97082
at equilibrium	3.12		

* Group B

Table C.2.3* Drying data for "1% (w/v) ascorbic acid treated" artichoke hearts.

T_{db} = 70ºC. T_{wb} = 28ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	27.96	1.000000	0.00000
5	24.59	0.864930	-0.14511
10	23.20	0.809218	-0.21169
15	20.78	0.712224	-0.33936
20	19.34	0.654509	-0.42387
25	18.03	0.602004	-0.50749
30	16.92	0.557515	-0.58427
35	15.90	0.516633	-0.66042
40	14.97	0.479359	-0.73531
50	13.33	0.413627	-0.88279
60	11.99	0.359920	-1.02187
70	10.76	0.310621	-1.16918
80	9.67	0.266934	-1.32075
90	8.71	0.228457	-1.47641
100	7.83	0.193186	-1.64410
110	7.06	0.162325	-1.81816
120	6.37	0.134669	-2.00493
130	5.77	0.110621	-2.20164
140	5.27	0.090581	-2.40151
150	4.84	0.073347	-2.61256
160	4.48	0.058918	-2.83161
180	3.94	0.037275	-3.28944
200	3.56	0.022044	-3.81471
220	3.35	0.013627	-4.29568
240	3.25	0.009619	-4.64399
260	3.17	0.006413	-5.04946
280	3.13	0.004810	-5.33714
300	3.10	0.003607	-5.62482
320	3.09	0.003206	-5.74260
340	3.05	0.001603	-6.43575
360	3.04	0.001202	-6.72343
380	3.01	0.000000	
400	3.01	0.000000	

* Group A

Table C.3.1* Drying data for "1% (w/v) sodium bisulfite treated" artichoke hearts. T_{db} = 50ºC. T_{wb} = 23ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	21.16	1.000000	0.00000
5	19.22	0.896478	-0.10928
10	17.76	0.818570	-0.20020
15	16.54	0.753469	-0.28307
20	15.59	0.702775	-0.35272
25	14.86	0.663821	-0.40974
30	14.25	0.631270	-0.46002
35	13.72	0.602988	-0.50586
40	13.27	0.578975	-0.54650
50	12.46	0.535752	-0.62408
60	11.81	0.501067	-0.69101
70	11.20	0.468517	-0.75818
80	10.65	0.439168	-0.82287
90	10.13	0.411419	-0.88814
100	9.62	0.384205	-0.95658
110	9.13	0.358058	-1.02706
120	8.69	0.334578	-1.09488
140	7.86	0.290288	-1.23688
160	7.13	0.251334	-1.38097
180	6.46	0.215582	-1.53442
200	5.87	0.184098	-1.69229
220	5.31	0.154216	-1.86940
240	4.84	0.129136	-2.04689
260	4.43	0.107257	-2.23253
280	4.08	0.088581	-2.42384
300	3.79	0.073106	-2.61585
320	3.56	0.060832	-2.79963
340	3.36	0.050160	-2.99254
360	3.20	0.041622	-3.17912
380	3.06	0.034152	-3.37695
at equilibrium	2.42		

* Group B

Table C.3.2* Drying data for "1% (w/v) sodium bisulfite treated" artichoke hearts. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	weight (g)	$(X_t\text{-}X^*)/(X_0\text{-}X^*)$	$\ln((X_t\text{-}X^*)/(X_0\text{-}X^*))$
0	17.78	1.000000	0.00000
5	15.68	0.852735	-0.15931
10	14.07	0.739832	-0.30133
15	12.88	0.656381	-0.42101
20	11.95	0.591164	-0.52566
25	11.20	0.538569	-0.61884
30	10.59	0.495792	-0.70160
35	10.04	0.457223	-0.78258
40	9.58	0.424965	-0.85575
50	8.79	0.369565	-0.99543
60	8.12	0.322581	-1.13140
70	7.52	0.280505	-1.27116
80	7.01	0.244741	-1.40756
90	6.54	0.211781	-1.55220
100	6.12	0.182328	-1.70195
110	5.76	0.157083	-1.85098
120	5.44	0.134642	-2.00513
140	4.94	0.099579	-2.30680
160	4.55	0.072230	-2.62790
180	4.28	0.053296	-2.93190
200	4.09	0.039972	-3.21958
220	3.95	0.030154	-3.50143
240	3.85	0.023142	-3.76612
260	3.78	0.018233	-4.00453
280	3.73	0.014727	-4.21811
300	3.69	0.011921	-4.42942
310	3.66	0.009818	-4.62357
at equilibrium	3.52		

* Group B

Table C.3.3* Drying data for “1% (w/v) sodium bisulfite treated” artichoke hearts. T_{db} = 70ºC. T_{wb} = 28ºC.

time (min)	weight (g)	$(X_t\text{-}X^*)/(X_0\text{-}X^*)$	$\ln((X_t\text{-}X^*)/(X_0\text{-}X^*))$
0	52.55	1.000000	0.00000
5	47.55	0.890830	-0.11560
10	42.62	0.783188	-0.24438
15	40.26	0.731659	-0.31244
20	38.21	0.686900	-0.37557
25	36.54	0.650437	-0.43011
30	34.76	0.611572	-0.49172
35	33.39	0.581659	-0.54187
40	32.06	0.552620	-0.59308
50	30.19	0.511790	-0.66984
60	28.18	0.467904	-0.75949
70	26.32	0.427293	-0.85029
80	24.67	0.391266	-0.93837
90	23.12	0.357424	-1.02883
100	21.69	0.326201	-1.12024
110	20.37	0.297380	-1.21274
120	19.17	0.271179	-1.30498
130	18.03	0.246288	-1.40125
140	16.96	0.222926	-1.50092
150	15.97	0.201310	-1.60291
160	15.06	0.181441	-1.70682
170	14.20	0.162664	-1.81607
180	13.37	0.144541	-1.93419
190	12.62	0.128166	-2.05443
200	11.93	0.113100	-2.17948
220	10.78	0.087991	-2.43052
240	9.80	0.066594	-2.70914
260	9.03	0.049782	-3.00011
280	8.45	0.037118	-3.29366
300	8.02	0.027729	-3.58527
320	7.71	0.020961	-3.86511
340	7.49	0.016157	-4.12539
360	7.34	0.012882	-4.35192
380	7.23	0.010480	-4.55825
400	7.14	0.008515	-4.76589
420	7.07	0.006987	-4.96372
at equilibrium	6.75		

* Group A

ADDITIONAL EXPERIMENTAL DRYING RESULTS

1% (w/v) Citric Acid, 2% (w/v) Ascorbic Acid, 2% (w/v) Sodium Bisulfite, Blanching for 15 Minutes

Table C.4.1* Drying data for "1% (w/v) citric acid treated" artichoke hearts. T_{db} = 50ºC. T_{wb} = 23ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	23.83	1.000000	0.00000
5	21.61	0.892546	-0.11368
10	20.10	0.819458	-0.19911
15	19.00	0.766215	-0.26629
20	18.18	0.726525	-0.31948
25	17.55	0.696031	-0.36236
30	17.07	0.672798	-0.39631
35	16.65	0.652469	-0.42699
40	16.29	0.635044	-0.45406
50	15.64	0.603582	-0.50487
60	15.03	0.574056	-0.55503
70	14.48	0.547435	-0.60251
80	13.95	0.521781	-0.65051
90	13.44	0.497096	-0.69897
100	12.98	0.474831	-0.74480
110	12.50	0.451597	-0.79496
120	12.04	0.429332	-0.84552
140	11.24	0.390610	-0.94005
160	10.48	0.353824	-1.03896
180	9.74	0.318006	-1.14569
200	9.08	0.286060	-1.25155
220	8.46	0.256050	-1.36238
240	7.86	0.227009	-1.48277
260	7.32	0.200871	-1.60509
280	6.82	0.176670	-1.73347
300	6.36	0.154405	-1.86818
320	5.93	0.133591	-2.01297
340	5.54	0.114714	-2.16531
360	5.18	0.097289	-2.33006
380	4.86	0.081801	-2.50347
400	4.56	0.067280	-2.69890
420	4.30	0.054695	-2.90598
440	4.08	0.044046	-3.12251
460	3.90	0.035334	-3.34291
at equilibrium	3.17		

* Group B

Table C.4.2* Drying data for "2% (w/v) ascorbic acid treated" artichoke hearts.

T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	weight (g)	$(X_t\text{-}X^*)/(X_0\text{-}X^*)$	$\ln((X_t\text{-}X^*)/(X_0\text{-}X^*))$
0	13.06	1.000000	0.00000
5	11.15	0.824125	-0.19343
10	9.82	0.701657	-0.35431
15	8.87	0.614180	-0.48747
20	8.08	0.541436	-0.61353
25	7.47	0.485267	-0.72306
30	6.96	0.438306	-0.82484
35	6.51	0.396869	-0.92415
40	6.10	0.359116	-1.02411
50	5.45	0.299263	-1.20643
60	4.92	0.250460	-1.38445
70	4.48	0.209945	-1.56091
80	4.10	0.174954	-1.74323
90	3.78	0.145488	-1.92766
100	3.49	0.118785	-2.13044
110	3.28	0.099448	-2.30813
120	3.09	0.081952	-2.50162
140	2.81	0.056169	-2.87938
160	2.63	0.039595	-3.22906
180	2.50	0.027624	-3.58906
200	2.41	0.019337	-3.94573
220	2.35	0.013812	-4.28221
240	2.31	0.010129	-4.59236
260	2.27	0.006446	-5.04435
280	2.25	0.004604	-5.38082
at equilibrium	2.20		

* Group C

Table C.4.3* Drying data for “2% (w/v) sodium bisulfite treated” artichoke hearts. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	**weight (g)**	**$(X_t-X^*)/(X_0-X^*)$**	**$\ln((X_t-X^*)/(X_0-X^*))$**
0	17.54	1.000000	0.00000
5	15.28	0.854756	-0.15694
10	13.64	0.749357	-0.28854
15	12.50	0.676093	-0.39143
20	11.50	0.611825	-0.49131
25	10.68	0.559126	-0.58138
30	9.96	0.512853	-0.66777
35	9.30	0.470437	-0.75409
40	8.72	0.433162	-0.83664
50	7.74	0.370180	-0.99377
60	6.96	0.320051	-1.13927
70	6.30	0.277635	-1.28145
80	5.68	0.237789	-1.43637
90	5.13	0.202442	-1.59730
100	4.64	0.170951	-1.76638
110	4.22	0.143959	-1.93823
120	3.86	0.120823	-2.11343
140	3.24	0.080977	-2.51359
160	2.81	0.053342	-2.93103
180	2.52	0.034704	-3.36089
200	2.33	0.022494	-3.79453
220	2.19	0.013496	-4.30535
240	2.15	0.010925	-4.51666
260	2.10	0.007712	-4.86497
280	2.07	0.005784	-5.15265
at equilibrium	1.98		

* Group B

Table C.4.4* Drying data for "1% (w/v) sodium bisulfite treated and 15min. blanched" artichoke hearts. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	16.09	1.000000	0.00000
5	13.84	0.829027	-0.18750
10	12.31	0.712766	-0.33860
15	11.19	0.627660	-0.46576
20	10.38	0.566109	-0.56897
25	9.75	0.518237	-0.65732
30	9.20	0.476444	-0.74141
35	8.70	0.438450	-0.82451
40	8.26	0.405015	-0.90383
50	7.52	0.348784	-1.05330
60	6.91	0.302432	-1.19590
70	6.36	0.260638	-1.34462
80	5.88	0.224164	-1.49538
90	5.47	0.193009	-1.64502
100	5.12	0.166413	-1.79328
110	4.79	0.141337	-1.95661
120	4.48	0.117781	-2.13893
140	4.05	0.085106	-2.46385
160	3.71	0.059271	-2.82564
180	3.48	0.041793	-3.17502
200	3.32	0.029635	-3.51879
220	3.22	0.022036	-3.81506
240	3.14	0.015957	-4.13783
260	3.10	0.012918	-4.34914
280	3.05	0.009119	-4.69745
at equilibrium	2.93		

* Group C

EXPERIMENTAL AND CALCULATED DATA FOR DRYING OF DIFFERENT ARTICHOKE GROUPS (A, B, C)

Table C.5.1* Drying data for "water treated" artichoke hearts, group A.
T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	19.46	1.000000	0.00000
5	17.24	0.876254	-0.13210
10	15.42	0.774805	-0.25514
15	13.84	0.686734	-0.37581
20	12.50	0.612040	-0.49096
25	11.33	0.546823	-0.60363
30	10.35	0.492196	-0.70888
35	9.51	0.445373	-0.80884
40	8.75	0.403010	-0.90879
50	7.37	0.326087	-1.12059
60	6.23	0.262542	-1.33734
70	5.19	0.204571	-1.58684
80	4.32	0.156076	-1.85741
90	3.59	0.115385	-2.15948
100	2.99	0.081940	-2.50177
110	2.50	0.054627	-2.90724
120	2.16	0.035674	-3.33332
140	1.79	0.015050	-4.19637
160	1.65	0.007246	-4.92725
180	1.59	0.003902	-5.54629
200	1.56	0.002230	-6.10591
230	1.55	0.001672	-6.39359
250	1.53	0.000557	-7.49220
at equilibrium	1.52		

* Replicate of Table C.1.3, group B.

Table C.5.2* Drying data for "1% sodium bisulfite treated" artichoke hearts, group C. T_{db} = 60ºC. T_{wb} = 25ºC.

Time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	16.92	1.000000	0.00000
5	14.89	0.853430	-0.15849
10	13.26	0.735740	-0.30688
15	11.93	0.639711	-0.44674
20	10.96	0.569675	-0.56269
25	10.06	0.504693	-0.68380
30	9.33	0.451986	-0.79411
35	8.74	0.409386	-0.89310
40	8.13	0.365343	-1.00692
50	7.19	0.297473	-1.21243
60	6.43	0.242599	-1.41634
70	5.68	0.188448	-1.66894
80	5.19	0.153069	-1.87687
90	4.78	0.123466	-2.09179
100	4.46	0.100361	-2.29898
110	4.20	0.081588	-2.50607
120	4.02	0.068592	-2.67958
140	3.70	0.045487	-3.09032
160	3.50	0.031047	-3.47226
180	3.36	0.020939	-3.86616
200	3.29	0.015884	-4.14241
220	3.24	0.012274	-4.40024
240	3.20	0.009386	-4.66851
260	3.17	0.007220	-4.93087
280	3.14	0.005054	-5.28755
at equilibrium	3.07		

*Replicate of Table C.3.2, group B.

Table C.5.3* Drying data for "1% sodium bisulfite treated" artichoke hearts, group C. T_{db} = 70ºC. T_{wb} = 28ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	25.57	1.000000	0.00000
5	22.30	0.835430	-0.17981
10	20.29	0.734273	-0.30887
15	18.81	0.659789	-0.41584
20	17.65	0.601409	-0.50848
25	16.68	0.552592	-0.59314
30	15.83	0.509814	-0.67371
35	15.12	0.474082	-0.74638
40	14.49	0.442375	-0.81560
50	13.45	0.390035	-0.94152
60	12.55	0.344741	-1.06496
70	11.78	0.305989	-1.18421
80	11.10	0.271766	-1.30281
90	10.51	0.242073	-1.41851
100	9.96	0.214394	-1.53994
110	9.48	0.190237	-1.65949
120	9.06	0.169099	-1.77727
140	8.34	0.132864	-2.01843
160	7.78	0.104680	-2.25684
180	7.35	0.083040	-2.48844
200	7.00	0.065425	-2.72685
220	6.73	0.051837	-2.95965
240	6.54	0.042275	-3.16356
260	6.38	0.034222	-3.37487
280	6.25	0.027680	-3.58705
300	6.14	0.022144	-3.81019
320	6.07	0.018621	-3.98346
340	6.01	0.015601	-4.16039
at equilibrium	5.70		

* Replicate of Table C.3.3, group A.

EXPERIMENTAL AND CALCULATED DATA FOR DRYING OF DEEPLY SCRAPED AND HALF ARTICHOKES

Table C.6.1[*,**] Drying data for "1% ascorbic acid treated" artichoke hearts, deeply scraped. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	14.17	1.000000	0.00000
5	12.30	0.849194	-0.16347
10	11.01	0.745161	-0.29415
15	9.88	0.654032	-0.42460
20	8.89	0.574194	-0.55479
25	8.05	0.506452	-0.68033
30	7.44	0.457258	-0.78251
35	6.89	0.412903	-0.88454
40	6.42	0.375000	-0.98083
50	5.64	0.312097	-1.16444
60	4.95	0.256452	-1.36082
70	4.37	0.209677	-1.56219
80	3.89	0.170968	-1.76628
90	3.49	0.138710	-1.97537
100	3.15	0.111290	-2.19561
110	2.88	0.089516	-2.41334
120	2.65	0.070968	-2.64553
140	2.34	0.045968	-3.07982
160	2.13	0.029032	-3.53935
180	2.02	0.020161	-3.90399
200	1.94	0.013710	-4.28965
220	1.90	0.010484	-4.55792
240	1.87	0.008065	-4.82028
260	1.84	0.005645	-5.17696
at equilibrium	1.77		

* Group B

** Replicate of Table C.2.2, normal.

Table C.6.2[*,**] Drying data for "1% sodium bisulfite treated" artichoke hearts, 1st half. T_{db} = 60ºC. T_{wb} = 25ºC.

Time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	12.38	1.000000	0.00000
5	10.51	0.817561	-0.20143
10	9.14	0.683902	-0.37994
15	8.16	0.588293	-0.53053
20	7.43	0.517073	-0.65957
25	6.84	0.459512	-0.77759
30	6.36	0.412683	-0.88508
35	5.93	0.370732	-0.99228
40	5.58	0.336585	-1.08890
50	4.98	0.278049	-1.27996
60	4.49	0.230244	-1.46862
70	4.08	0.190244	-1.65945
80	3.76	0.159024	-1.83870
90	3.46	0.129756	-2.04210
100	3.22	0.106341	-2.24110
110	3.03	0.087805	-2.43264
120	2.87	0.072195	-2.62838
140	2.63	0.048780	-3.02042
160	2.48	0.034146	-3.37710
180	2.42	0.028293	-3.56515
200	2.32	0.018537	-3.98801
220	2.27	0.013659	-4.29339
240	2.23	0.009756	-4.62986
260	2.21	0.007805	-4.85301
280	2.19	0.005854	-5.14069
at equilibrium	2.13		

* Group C

** Replicate of Table C.5.4, whole.

Table C.6.3* Drying data for "1% sodium bisulfite treated" artichoke hearts, 2nd half. T_{db} = 25ºC. T_{wb} = 15ºC

Time (min)	weight (g)	$(X_t-X^*)/(X_0-X^*)$	$\ln((X_t-X^*)/(X_0-X^*))$
0	12.76	1.000000	0.00000
5	12.42	0.967526	-0.03301
10	12.30	0.956065	-0.04493
20	12.14	0.940783	-0.06104
30	11.99	0.926457	-0.07639
40	11.85	0.913085	-0.09093
50	11.71	0.899713	-0.10568
60	11.56	0.885387	-0.12173
80	11.31	0.861509	-0.14907
100	11.01	0.832856	-0.18289
120	10.76	0.808978	-0.21198
140	10.51	0.785100	-0.24194
160	10.24	0.759312	-0.27534
180	9.99	0.735435	-0.30729
200	9.73	0.710602	-0.34164
220	9.47	0.685769	-0.37721
240	9.22	0.661891	-0.41265
260	8.97	0.638013	-0.44940
280	8.74	0.616046	-0.48443
at equilibrium	2.29		

* Group C

APPENDIX D

EXPERIMENTAL AND CALCULATED DATA FOR REHYDRATION OF ARTICHOKE HEARTS

Table D.1.1* Rehydration data at 20ºC for "water treated" artichoke hearts dried at T_{db} = 40ºC T_{wb} = 19ºC.

time (min)	time (h)	weight (g)	Xt (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	3.02	-	-
5	0.08333	4.34	0.43709	0.19066
10	0.16667	5.04	0.66887	0.24917
15	0.25000	5.60	0.85430	0.29264
20	0.33333	6.12	1.02649	0.32473
25	0.41667	6.61	1.18874	0.35051
30	0.50000	7.12	1.35762	0.36829
35	0.58333	7.55	1.50000	0.38889
40	0.66667	7.96	1.63576	0.40756
45	0.75000	8.37	1.77152	0.42336
50	0.83333	8.79	1.91060	0.43616
60	1.00000	9.43	2.12252	0.47114
70	1.16667	10.07	2.33444	0.49976
80	1.33333	10.63	2.51987	0.52913
90	1.50000	11.18	2.70199	0.55515
100	1.66667	11.75	2.89073	0.57656
120	2.00000	12.53	3.14901	0.63512
140	2.33333	13.30	3.40397	0.68547
160	2.66667	13.87	3.59272	0.74224
180	3.00000	14.35	3.75166	0.79965
200	3.33333	14.86	3.92053	0.85023
220	3.66667	15.21	4.03642	0.90839

* Group A

Table D.1.2* Rehydration data at 20ºC for "water treated" artichoke hearts dried at T_{db} = 50ºC T_{wb} = 23ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	1.91	-	-
5	0.08333	3.00	0.56250	0.14815
10	0.16667	3.63	0.89063	0.18713
15	0.25000	4.21	1.19271	0.20961
20	0.33333	4.66	1.42708	0.23358
25	0.41667	5.06	1.63542	0.25478
30	0.50000	5.39	1.80729	0.27666
35	0.58333	5.72	1.97917	0.29474
40	0.66667	6.11	2.18229	0.30549
45	0.75000	6.34	2.30208	0.32579
50	0.83333	6.66	2.46875	0.33755
60	1.00000	7.06	2.67708	0.37354
70	1.16667	7.45	2.88021	0.40506
80	1.33333	7.81	3.06771	0.43463
90	1.50000	8.10	3.21875	0.46602
100	1.66667	8.36	3.35417	0.49689
120	2.00000	8.78	3.57292	0.55977
140	2.33333	9.16	3.77083	0.61878
160	2.66667	9.46	3.92708	0.67905
180	3.00000	9.64	4.02083	0.74611
200	3.33333	9.84	4.12500	0.80808

* Group A

Table D.1.3* Rehydration data at 20ºC for “water treated” artichoke hearts dried at T_{db} = 60ºC T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.24	-	-
5	0.08333	3.34	0.47788	0.17438
10	0.16667	4.02	0.77876	0.21402
15	0.25000	4.58	1.02655	0.24353
20	0.33333	5.08	1.24779	0.26714
25	0.41667	5.59	1.47345	0.28278
30	0.50000	6.21	1.74779	0.28608
35	0.58333	6.75	1.98673	0.29362
40	0.66667	7.09	2.13717	0.31194
45	0.75000	7.50	2.31858	0.32347
50	0.83333	7.88	2.48673	0.33511
60	1.00000	8.48	2.75221	0.36334
70	1.16667	9.00	2.9823	0.39120
80	1.33333	9.47	3.19027	0.41794
90	1.50000	9.95	3.40265	0.44083
100	1.66667	10.34	3.57522	0.46617
120	2.00000	11.01	3.87168	0.51657
140	2.33333	11.53	4.10177	0.56886
160	2.66667	11.92	4.27434	0.62388
180	3.00000	12.42	4.49558	0.66732
200	3.33333	12.83	4.67699	0.71271

* Group A

Table D.1.4* Rehydration data at 20ºC for "water treated" artichoke hearts dried at T_{db} = 70ºC T_{wb} = 28ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.10	-	-
5	0.08333	3.29	0.58173	0.14325
10	0.16667	4.00	0.92308	0.18056
15	0.25000	4.70	1.25962	0.19847
20	0.33333	5.31	1.55288	0.21465
25	0.41667	5.87	1.82212	0.22867
30	0.50000	6.35	2.05288	0.24356
35	0.58333	6.79	2.26442	0.25761
40	0.66667	7.20	2.46154	0.27083
45	0.75000	7.53	2.62019	0.28624
50	0.83333	7.95	2.82212	0.29529
60	1.00000	8.46	3.06731	0.32602
70	1.16667	8.94	3.29808	0.35374
80	1.33333	9.45	3.54327	0.37630
90	1.50000	9.83	3.72596	0.40258
100	1.66667	10.19	3.89904	0.42746
120	2.00000	10.72	4.15385	0.48148
140	2.33333	11.09	4.33173	0.53866
160	2.66667	11.51	4.53365	0.58819
180	3.00000	11.90	4.72115	0.63544
200	3.33333	12.22	4.87500	0.68376
	24.00000	15.12	6.26923	3.82822

* Group A

Table D.2.1* Rehydration data at 20ºC for "1% (w/v) ascorbic acid treated" artichoke hearts dried at T_{db} = 50ºC T_{wb} = 23ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.29	-	-
5	0.08333	3.46	0.49784	0.16739
10	0.16667	4.07	0.76190	0.21875
15	0.25000	4.66	1.01732	0.24574
20	0.33333	5.15	1.22944	0.27113
25	0.41667	5.61	1.42857	0.29167
30	0.50000	6.04	1.61472	0.30965
35	0.58333	6.46	1.79654	0.32470
40	0.66667	6.83	1.95671	0.34071
45	0.75000	7.17	2.10390	0.35648
50	0.83333	7.49	2.24242	0.37162
60	1.00000	8.02	2.47186	0.40455
70	1.16667	8.44	2.65368	0.43964
80	1.33333	8.85	2.83117	0.47095
90	1.50000	9.24	3.00000	0.50000
100	1.66667	9.51	3.11688	0.53472
120	2.00000	10.09	3.36797	0.59383
140	2.33333	10.58	3.58009	0.65175
160	2.66667	10.91	3.72294	0.71628
180	3.00000	11.27	3.87879	0.77344
200	3.33333	11.56	4.00433	0.83243
220	3.66667	11.81	4.11255	0.89158

* Group B

Table D.2.2* Rehydration data at 20ºC for "1% (w/v) ascorbic acid treated" artichoke hearts dried at T_{db} = 60ºC T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	3.12	-	-
5	0.08333	4.34	0.38658	0.21556
10	0.16667	4.95	0.58147	0.28663
15	0.25000	5.54	0.76997	0.32469
20	0.33333	6.07	0.93930	0.35488
25	0.41667	6.54	1.08946	0.38245
30	0.50000	7.07	1.25879	0.39721
35	0.58333	7.47	1.38658	0.42070
40	0.66667	7.90	1.52396	0.43746
45	0.75000	8.24	1.63259	0.45939
50	0.83333	8.63	1.75719	0.47424
60	1.00000	9.18	1.93291	0.51736
70	1.16667	9.71	2.10224	0.55496
80	1.33333	10.17	2.24920	0.59280
90	1.50000	10.66	2.40575	0.62351
100	1.66667	11.12	2.55272	0.65290
120	2.00000	11.84	2.78275	0.71871
140	2.33333	12.38	2.95527	0.78955
160	2.66667	12.95	3.13738	0.84997
180	3.00000	13.45	3.29712	0.90988
200	3.33333	13.95	3.45687	0.96426
	24.00000	17.34	4.53994	5.28642

* Group B

Table D.2.3*Rehydration data at 20ºC for "1% (w/v) ascorbic acid treated" artichoke hearts dried at T_{db} = 70ºC T_{wb} = 28ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	3.01	-	-
5	0.08333	4.22	0.39735	0.20972
10	0.16667	4.86	0.60927	0.27355
15	0.25000	5.42	0.79470	0.31458
20	0.33333	5.95	0.97020	0.34357
25	0.41667	6.42	1.12583	0.3701
30	0.50000	6.9	1.28477	0.38918
35	0.58333	7.35	1.43377	0.40685
40	0.66667	7.72	1.55629	0.42837
45	0.75000	8.11	1.68543	0.44499
50	0.83333	8.51	1.81788	0.45841
60	1.00000	9.13	2.02318	0.49427
70	1.16667	9.65	2.19536	0.53142
80	1.33333	10.08	2.33775	0.57035
90	1.50000	10.48	2.47020	0.60724
100	1.66667	10.91	2.61258	0.63794
120	2.00000	11.55	2.82450	0.70809
140	2.33333	12.07	2.99669	0.77864
160	2.66667	12.57	3.16225	0.84328
180	3.00000	13.03	3.31457	0.90509
200	3.33333	13.46	3.45695	0.96424
	24.00000	18.29	5.05629	4.74656

* Group A

Table D.3.1* Rehydration data at 20ºC for “1% (w/v) sodium bisulfite treated” artichoke hearts dried at T_{db} = 50ºC T_{wb} = 23ºC.

time (min)	time (h)	Weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.42	-	-
5	0.08333	3.76	0.54733	0.15226
10	0.16667	4.46	0.83539	0.19951
15	0.25000	4.98	1.04938	0.23824
20	0.33333	5.50	1.26337	0.26384
25	0.41667	6.00	1.46914	0.28361
30	0.50000	6.44	1.65021	0.30299
35	0.58333	6.85	1.81893	0.32070
40	0.66667	7.23	1.97531	0.33750
45	0.75000	7.57	2.11523	0.35457
50	0.83333	7.89	2.24691	0.37088
60	1.00000	8.51	2.50206	0.39967
70	1.16667	9.00	2.70370	0.43151
80	1.33333	9.43	2.88066	0.46286
90	1.50000	9.82	3.04115	0.49323
100	1.66667	10.17	3.18519	0.52326
120	2.00000	10.75	3.42387	0.58413
140	2.33333	11.22	3.61728	0.64505
160	2.66667	11.61	3.77778	0.70588
180	3.00000	12.03	3.95062	0.75938
200	3.33333	12.26	4.04527	0.82401

* Group B

Table D.3.2* Rehydration data at 20ºC for “1% (w/v) sodium bisulfite treated” artichoke hearts dried at T_{db} = 60ºC T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	3.52	-	-
5	0.08333	4.92	0.39773	0.20952
10	0.16667	5.53	0.57102	0.29187
15	0.25000	6.10	0.73295	0.34109
20	0.33333	6.56	0.86364	0.38596
25	0.41667	7.01	0.99148	0.42025
30	0.50000	7.43	1.11080	0.45013
35	0.58333	7.78	1.21023	0.48200
40	0.66667	8.10	1.30114	0.51237
45	0.75000	8.45	1.40057	0.53550
50	0.83333	8.82	1.50568	0.55346
60	1.00000	9.40	1.67045	0.59864
70	1.16667	9.89	1.80966	0.64469
80	1.33333	10.37	1.94602	0.68516
90	1.50000	10.75	2.05398	0.73029
100	1.66667	11.19	2.17898	0.76488
120	2.00000	11.82	2.35795	0.84819
140	2.33333	12.40	2.52273	0.92492
160	2.66667	12.91	2.66761	0.99965
180	3.00000	13.33	2.78693	1.07645
200	3.33333	13.71	2.89489	1.15146
220	3.66667	14.08	3.00000	1.22222
240	4.00000	14.39	3.08807	1.29531
	24.00000	16.38	3.65341	6.56921

* Group B

Table D.3.3* Rehydration data at 20ºC for "1% (w/v) sodium bisulfite treated" artichoke hearts dried at T_{db} = 70ºC T_{wb} = 28ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	6.75	-	-
5	0.08333	9.24	0.36686	0.22715
10	0.16667	10.51	0.55473	0.30044
15	0.25000	11.48	0.69822	0.35805
20	0.33333	12.29	0.81805	0.40747
25	0.41667	12.93	0.91272	0.45651
30	0.50000	13.60	1.01183	0.49415
35	0.58333	14.16	1.09467	0.53288
40	0.66667	14.93	1.20858	0.55161
45	0.75000	15.34	1.26923	0.59091
50	0.83333	15.93	1.35651	0.61432
60	1.00000	16.78	1.48225	0.67465
70	1.16667	17.64	1.60947	0.72488
80	1.33333	18.33	1.71154	0.77903
90	1.50000	19.06	1.81953	0.82439
100	1.66667	19.75	1.92160	0.86733
120	2.00000	20.84	2.08284	0.96023
140	2.33333	21.77	2.22041	1.05085
160	2.66667	22.77	2.36834	1.12596
	24.00000	33.27	3.92160	6.11995

* Group A

ADDITIONAL EXPERIMENTAL REHYDRATION RESULTS

1% (w/v) Citric Acid, 2% (w/v) Ascorbic Acid, 2% (w/v) Sodium Bisulfite, Blanching for 15 Minutes, Rehydration at 40ºC

Table D.4.1* Rehydration data at 20ºC for "1% (w/v) citric acid treated" artichoke hearts dried at T_{db} = 50ºC T_{wb} = 23ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	3.17	-	-
5	0.08333	4.62	0.44828	0.18590
10	0.16667	5.43	0.70219	0.23735
15	0.25000	6.20	0.94357	0.26495
20	0.33333	6.77	1.12226	0.29702
25	0.41667	7.35	1.30408	0.31951
30	0.50000	7.85	1.46082	0.34227
35	0.58333	8.33	1.61129	0.36203
40	0.66667	8.77	1.74922	0.38112
45	0.75000	9.19	1.88088	0.39875
50	0.83333	9.56	1.99687	0.41732
60	1.00000	10.17	2.18809	0.45702
70	1.16667	10.75	2.36991	0.49228
80	1.33333	11.20	2.51097	0.53100
90	1.50000	11.64	2.64890	0.56627
100	1.66667	12.07	2.78370	0.59872
120	2.00000	12.72	2.98746	0.66946
140	2.33333	13.24	3.15047	0.74063
160	2.66667	13.67	3.28527	0.81170
180	3.00000	14.00	3.38871	0.88529
200	3.33333	14.37	3.50470	0.95110
220	3.66667	14.67	3.59875	1.01887

* Group B

Table D.4.2[*] Rehydration data at 20ºC for "2% (w/v) ascorbic acid treated" artichoke hearts dried at T_{db} = 60ºC T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.20	-	-
5	0.08333	3.30	0.50000	0.16667
10	0.16667	3.95	0.79545	0.20952
15	0.25000	4.53	1.05909	0.23605
20	0.33333	5.02	1.28182	0.26005
25	0.41667	5.51	1.50455	0.27694
30	0.50000	5.88	1.67273	0.29891
35	0.58333	6.26	1.84545	0.31609
40	0.66667	6.60	2.00000	0.33333
45	0.75000	6.94	2.15455	0.34810
50	0.83333	7.18	2.26364	0.36814
60	1.00000	7.76	2.52727	0.39568
70	1.16667	8.16	2.70909	0.43065
80	1.33333	8.55	2.88636	0.46194
90	1.50000	8.85	3.02273	0.49624
100	1.66667	9.13	3.15000	0.52910
120	2.00000	9.69	3.40455	0.58745
140	2.33333	10.13	3.60455	0.64733
160	2.66667	10.46	3.75455	0.71025
180	3.00000	10.71	3.86818	0.77556
200	3.33333	10.98	3.99091	0.83523

* Group C

Table D.4.3* Rehydration data at 20ºC for "2% (w/v) sodium bisulfite treated" artichoke hearts dried at T_{db} = 60ºC T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	1.98	-	-
5	0.08333	3.16	0.58794	0.14174
10	0.16667	3.84	0.92965	0.17928
15	0.25000	4.44	1.23116	0.20306
20	0.33333	4.98	1.50251	0.22185
25	0.41667	5.46	1.74372	0.23895
30	0.50000	5.91	1.96985	0.25383
35	0.58333	6.38	2.20603	0.26443
40	0.66667	6.74	2.38693	0.27930
45	0.75000	7.03	2.53266	0.29613
50	0.83333	7.31	2.67337	0.31172
60	1.00000	7.92	2.97990	0.33558
70	1.16667	8.34	3.19095	0.36562
80	1.33333	8.77	3.40704	0.39135
90	1.50000	9.05	3.54774	0.42280
100	1.66667	9.34	3.69347	0.45125
120	2.00000	9.98	4.01508	0.49812
140	2.33333	10.43	4.24121	0.55016
160	2.66667	10.74	4.39698	0.60648
180	3.00000	11.03	4.54271	0.66040
200	3.33333	11.35	4.70352	0.70869

* Group B

Table D.4.4* Rehydration data at 20ºC for “1% (w/v) sodium bisulfite treated and 15 min. blanched” artichoke hearts dried at T_{db} = 60ºC T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.93	-	-
5	0.08333	4.55	0.55822	0.14928
10	0.16667	5.47	0.87329	0.19085
15	0.25000	6.31	1.16096	0.21534
20	0.33333	6.95	1.38014	0.24152
25	0.41667	7.53	1.57877	0.26392
30	0.50000	8.12	1.78082	0.28077
35	0.58333	8.70	1.97945	0.29469
40	0.66667	9.13	2.12671	0.31347
45	0.75000	9.51	2.25685	0.33232
50	0.83333	9.94	2.40411	0.34663
60	1.00000	10.70	2.66438	0.37532
70	1.16667	11.28	2.86301	0.40750
80	1.33333	11.76	3.02740	0.44042
90	1.50000	12.28	3.20548	0.46795
100	1.66667	12.75	3.36644	0.49508
120	2.00000	13.40	3.58904	0.55725
140	2.33333	13.93	3.77055	0.61883
160	2.66667	14.50	3.96575	0.67242
180	3.00000	14.98	4.13014	0.72637
200	3.33333	15.30	4.23973	0.78621
	24.00000	16.74	4.73288	5.07091

* Group C

EXPERIMENTAL AND CALCULATED DATA FOR REHYDRATION OF DIFFERENT ARTICHOKE GROUPS (A, B, C)

Table D.5.1* Rehydration data at 20ºC for "water treated" artichoke hearts, group A. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	1.52	-	-
5	0.08333	2.65	0.74342	0.11209
10	0.16667	3.34	1.19737	0.13919
15	0.25000	3.93	1.58553	0.15768
20	0.33333	4.48	1.94737	0.17117
25	0.41667	4.95	2.25658	0.18465
30	0.50000	5.42	2.56579	0.19487
35	0.58333	5.84	2.84211	0.20525
40	0.66667	6.19	3.07237	0.21699
45	0.75000	6.45	3.24342	0.23124
50	0.83333	6.74	3.43421	0.24266
60	1.00000	7.30	3.80263	0.26298
70	1.16667	7.64	4.02632	0.28976
80	1.33333	7.97	4.24342	0.31421
90	1.50000	8.40	4.52632	0.33140
100	1.66667	8.65	4.69079	0.35531
120	2.00000	9.17	5.03289	0.39739
140	2.33333	9.50	5.25000	0.44444
160	2.66667	9.95	5.54605	0.48082
180	3.00000	10.26	5.75000	0.52174
200	3.33333	10.85	6.13816	0.54305
220	3.66667	11.21	6.37500	0.57516

* Replicate of Table D.1.3, group B.

Table D.5.2* Rehydration data at 20ºC for "1% sodium bisulfite treated" artichoke hearts, group C. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	3.07	-	-
5	0.08333	4.80	0.55844	0.14922
10	0.16667	5.75	0.86688	0.19226
15	0.25000	6.63	1.15260	0.21690
20	0.33333	7.37	1.39286	0.23932
25	0.41667	8.05	1.61364	0.25822
30	0.50000	8.63	1.80195	0.27748
35	0.58333	9.23	1.99675	0.29214
40	0.66667	9.77	2.17208	0.30693
45	0.75000	10.20	2.31169	0.32444
50	0.83333	10.69	2.47078	0.33728
60	1.00000	11.44	2.71429	0.36842
70	1.16667	12.11	2.93182	0.39793
80	1.33333	12.76	3.14286	0.42424
90	1.50000	13.21	3.28896	0.45607
100	1.66667	13.69	3.44481	0.48382
120	2.00000	14.47	3.69805	0.54083
140	2.33333	15.17	3.92532	0.59443
160	2.66667	15.66	4.08442	0.65289
180	3.00000	16.12	4.23377	0.70859
200	3.33333	16.38	4.31818	0.77193

* Replicate of Table D.3.2, group B.

Table D.5.3* Rehydration data at 20ºC for "1% sodium bisulfite treated" artichoke hearts, group C. T_{db} = 70ºC. T_{wb} = 28ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	5.70	-	-
5	0.08333	7.59	0.33392	0.24956
10	0.16667	8.59	0.50967	0.32701
15	0.25000	9.31	0.63620	0.39296
20	0.33333	9.95	0.74868	0.44523
25	0.41667	10.56	0.85589	0.48682
30	0.50000	11.05	0.94200	0.53078
35	0.58333	11.53	1.02636	0.56835
40	0.66667	12.03	1.11424	0.59832
45	0.75000	12.47	1.19156	0.62942
50	0.83333	12.98	1.28120	0.65043
60	1.00000	13.71	1.40949	0.70948
70	1.16667	14.42	1.53427	0.76040
80	1.33333	15.13	1.65905	0.80367
90	1.50000	15.78	1.77329	0.84589
100	1.66667	16.46	1.89279	0.88053
120	2.00000	17.56	2.08612	0.95872
140	2.33333	18.55	2.26011	1.03240
160	2.66667	19.49	2.42531	1.09952
180	3.00000	20.35	2.57645	1.16439
200	3.33333	21.12	2.71178	1.22921
210	3.50000	21.59	2.79438	1.25252
	24.00000	28.21	3.95782	6.06394

* Replicate of Table D.3.3, group A.

EXPERIMENTAL AND CALCULATED DATA FOR REHYDRATION OF DEEPLY SCRAPED AND HALF ARTICHOKES

Table D.6.1[*,**] Rehydration data at 20ºC for "1% ascorbic acid treated" artichoke hearts, deeply scraped. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	1.77	-	-
5	0.08333	2.77	0.55618	0.14983
10	0.16667	3.39	0.90449	0.18427
15	0.25000	3.98	1.23596	0.20227
20	0.33333	4.52	1.53933	0.21655
25	0.41667	5.04	1.83146	0.22751
30	0.50000	5.46	2.06742	0.24185
35	0.58333	5.84	2.28090	0.25575
40	0.66667	6.29	2.53371	0.26312
45	0.75000	6.59	2.70225	0.27755
50	0.83333	6.98	2.92135	0.28526
60	1.00000	7.44	3.17978	0.31449
70	1.16667	7.95	3.46629	0.33657
80	1.33333	8.39	3.71348	0.35905
90	1.50000	8.68	3.87640	0.38696
100	1.66667	9.05	4.08427	0.40807
120	2.00000	9.63	4.41011	0.45350
140	2.33333	10.14	4.69663	0.49681
160	2.66667	10.59	4.94944	0.53878
180	3.00000	10.91	5.12921	0.58488
200	3.33333	11.28	5.33708	0.62456
220	3.66667	11.64	5.53933	0.66193

* Group B

** Replicate of Table D.2.2, normal.

Table D.6.2[*,**] Rehydration data at 20ºC for "1% sodium bisulfite treated" artichoke hearts, 1st half. T_{db} = 60ºC. T_{wb} = 25ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.13	-	-
5	0.08333	3.42	0.60563	0.13760
10	0.16667	4.06	0.90610	0.18394
15	0.25000	4.61	1.16432	0.21472
20	0.33333	5.09	1.38967	0.23986
25	0.41667	5.56	1.61033	0.25875
30	0.50000	5.97	1.80282	0.27734
35	0.58333	6.37	1.99061	0.29304
40	0.66667	6.75	2.16901	0.30736
45	0.75000	7.10	2.33333	0.32143
50	0.83333	7.46	2.50235	0.33302
60	1.00000	8.03	2.76995	0.36102
70	1.16667	8.58	3.02817	0.38527
80	1.33333	9.01	3.23005	0.41279
90	1.50000	9.45	3.43662	0.43648
100	1.66667	9.90	3.64789	0.45689
120	2.00000	10.62	3.98592	0.50177
140	2.33333	11.22	4.26761	0.54675
160	2.66667	11.79	4.53521	0.58799
180	3.00000	12.32	4.78404	0.62709
200	3.33333	12.66	4.94366	0.67426
220	3.66667	12.99	5.09859	0.71915

* Group C

** Replicate of Table D.5.4, whole.

Table D.6.3* Rehydration data at 20ºC for "1% sodium bisulfite treated" artichoke hearts, 2nd half. T_{db} = 25ºC. T_{wb} = 15ºC.

time (min)	time (h)	weight (g)	Xt (db) (mc-db)	t/(Xt-Xo) (h/mc-db)
0	0.00000	2.29	-	-
5	0.08333	3.14	0.37118	0.22451
10	0.16667	3.61	0.57642	0.28914
15	0.25000	4.05	0.76856	0.32528
20	0.33333	4.45	0.94323	0.35340
25	0.41667	4.83	1.10917	0.37566
30	0.50000	5.25	1.29258	0.38682
35	0.58333	5.63	1.45852	0.39995
40	0.66667	6.04	1.63755	0.40711
45	0.75000	6.43	1.80786	0.41486
50	0.83333	6.81	1.97380	0.42220
60	1.00000	7.39	2.22707	0.44902
70	1.16667	7.98	2.48472	0.46954
80	1.33333	8.50	2.71179	0.49168
90	1.50000	9.04	2.94760	0.50889
100	1.66667	9.53	3.16157	0.52716
120	2.00000	10.32	3.50655	0.57036
140	2.33333	11.00	3.80349	0.61347
160	2.66667	11.63	4.07860	0.65382
180	3.00000	12.18	4.31878	0.69464
200	3.33333	12.60	4.50218	0.74038

* Group C

APPENDIX E

EXPERIMENTAL AND CALCULATED DATA FOR COLOR

Table E.1.1 Color data for fresh artichoke heart (reference).

	L_0	a_0	b_0	dL	dE	dBI
Outer part	79.3	2	25	0	0	0
Inner part	77.6	5.1	28.9	0	0	0

Table E.1.2 Color data for artichoke hearts.

		L	a	b	ΔL	ΔE	ΔBI
70°C 1% $NaHSO_3$	Outer part	60.4	4.1	12.9	-18.9	22.5	-10.3
	Inner part	46.9	5.3	10.3	-30.7	35.9	-17.7
60°C 1% $NaHSO_3$	Outer part	60.6	6.5	13.3	-18.7	22.5	-6.6
	Inner part	61.4	2.3	14.4	-16.2	21.9	-21.4
50°C 1% $NaHSO_3$	Outer part	59.4	9.5	15.0	-19.9	23.5	1.5
	Inner part	67.1	7.3	18.0	-10.5	15.3	-11.7
70°C $C_6H_8O_6$	Outer part	52.1	5.2	18.3	-27.2	28.2	10.0
	Inner part	44.7	6.7	18.1	-32.9	34.7	11.5
60°C 1% $C_6H_8O_6$	Outer part	34.7	16.5	13.9	-44.6	48.2	45.2
	Inner part	34.5	16.9	14.9	-43.1	46.8	39.8
50°C 1% $C_6H_8O_6$	Outer part	39.8	10.4	14.1	-39.5	41.8	23.3
	Inner part	40.8	9.8	16.4	-36.8	39.1	17.7
70°C water treated	Outer part	43.2	4.5	17.0	-36.1	37.1	17.8
	Inner part	31.0	6.4	14.6	-46.6	48.8	26.9
60°C water treated	Outer part	42.5	8.4	20.3	-36.8	37.6	38.9
	Inner part	47.6	8.2	20.2	-30.0	31.4	16.4
50°C water treated	Outer part	46.8	8.9	18.9	-32.5	33.8	25.9
	Inner part	29.5	6.6	11.4	-48.1	51.4	14.0
40°C water treated	Outer part	30.4	10.3	13.1	-48.9	51.0	41.0
	Inner part	22.7	5.6	7.3	-54.9	59.0	5.8

ADDITIONAL EXPERIMENTAL COLOR RESULTS

1% (w/v) Citric Acid, 2% (w/v) Ascorbic Acid, 2% (w/v) Sodium Bisulfite, Blanching for 15 Minutes

Table E.2.1 Color data for "1% (w/v) citric acid treated" artichoke hearts dried at T_{db} = 50ºC. T_{wb} = 23ºC.

		L	a	b	ΔL	ΔE	ΔBI
50ºC 1% $C_6H_8O_7$	Outer part	37.8	8.97	17.3	-41.5	42.8	38.35
	Inner part	38.3	8.4	15.5	-39.3	41.7	16.63

Table E.2.2 Color data for "2% (w/v) ascorbic acid treated" artichoke hearts dried at T_{db} = 60ºC. T_{wb} = 25ºC.

		L	a	b	ΔL	ΔE	ΔBI
60ºC 2% $C_6H_8O_6$	Outer part	54	11.2	29.3	-25.3	27.3	51.8
	Inner part	59.3	9.3	23.8	-18.3	19.5	11.5

Table E.2.3 Color data for "2% (w/v) sodium bisulfite treated" artichoke hearts dried at T_{db} = 60ºC. T_{wb} = 25ºC.

		L	a	b	ΔL	ΔE	ΔBI
60ºC 2% $NaHSO_3$	Outer part	53.8	7.4	15.4	-25.5	27.8	4.45
	Inner part	57.8	12.4	13	-19.8	26.4	-9.7

Table E.2.4 Color data for "1% (w/v) sodium bisulfite treated" artichoke hearts dried at T_{db} = 60ºC. T_{wb} = 25ºC with 15 min. blanching.

		L	a	b	ΔL	ΔE	ΔBI
60ºC 1% $NaHSO_3$ 15min.blanching	Outer part	44.3	12.5	18.9	-35	37	36.3
	Inner part	56.2	14.8	9.5	-21.4	30.5	-13

EXPERIMENTAL AND CALCULATED DATA FOR COLOR OF DIFFERENT ARTICHOKE GROUPS (A, B, C)

Table E.3.1 Color data for "water treated" artichoke hearts, group A, group B. T_{db} = 60ºC. T_{wb} = 25ºC.

Group A		L	a	b	ΔL	ΔE	ΔBI
60ºC water treated	Outer part	36.9	12.9	14.4	-42.4	45	35.1
	Inner part	40.4	15.6	16.6	-37.2	40.6	29.4
Group B							
60ºC water treated	Outer part	42.5	8.4	20.3	-36.8	37.6	38.9
	Inner part	47.6	8.2	20.2	-30.0	31.4	16.4

Table E.3.2 Color data for "1% sodium bisulfite treated" artichoke hearts, group B, group C. T_{db} = 60ºC. T_{wb} = 25ºC.

Group B		L	a	b	ΔL	ΔE	ΔBI
60ºC 1% $NaHSO_3$	Outer part	60.6	6.5	13.3	-18.7	22.5	-6.6
	Inner part	61.4	2.3	14.4	-16.2	21.9	-21.4
Group C							
60ºC 1% $NaHSO_3$	Outer part	49.5	2.9	21.3	-29.8	30	20.2
	Inner part	59	2	20.1	-18.6	20.8	-7.2

Table E.3.3 Color data for "1% sodium bisulfite treated" artichoke hearts, group A, group C. T_{db} = 70ºC. T_{wb} = 28ºC.

Group A		L	a	b	ΔL	ΔE	ΔBI
70ºC 1% $NaHSO_3$	Outer part	60.4	4.1	12.9	-18.9	22.5	-10.3
	Inner part	46.9	5.3	10.3	-30.7	35.9	-17.7
Group C							
70ºC 1% $NaHSO_3$	Outer part	45.4	14	11.8	-33.9	38.3	13
	Inner part	45.2	12.8	6.7	-32.4	40	-15

EXPERIMENTAL AND CALCULATED DATA FOR COLOR OF DEEPLY SCRAPED AND HALF ARTICHOKES

Table E.4.1 Color data for "1% ascorbic acid treated" artichoke hearts, deeply scraped. $T_{db} = 60°C$. $T_{wb} = 25°C$.

		L	a	b	ΔL	ΔE	ΔBI
60ºC 1% $C_6H_8O_6$	Outer part	51.0	9.8	20.2	-28.3	29.7	24.8
	Inner part	48.9	15.9	20.2	-28.7	31.9	25.6

Table E.4.2 Color data for "1% ascorbic acid treated" artichoke hearts, normal.

$T_{db} = 60°C$. $T_{wb} = 25°C$.

		L	a	b	ΔL	ΔE	ΔBI
60ºC 1% $C_6H_8O_6$	Outer part	34.7	16.5	13.9	-44.6	48.2	45.2
	Inner part	34.5	16.9	14.9	-43.1	46.8	39.8

Table E.4.3 Color data for "1% sodium bisulfite treated" artichoke hearts, 1st half.

$T_{db} = 60°C$. $T_{wb} = 25°C$.

		L	a	b	ΔL	ΔE	ΔBI
60ºC 1% $NaHSO_3$ 1st half	Outer part	46.2	9	19.8	-33.1	34.2	30.3
	Inner part	57.2	5.9	17.6	-20.4	23.3	-6.7

Table E.4.4 Color data for "1% sodium bisulfite treated" artichoke hearts, whole.

$T_{db} = 60°C$. $T_{wb} = 25°C$.

		L	a	b	ΔL	ΔE	ΔBI
60ºC 1% $NaHSO_3$	Outer part	49.5	2.9	21.3	-29.8	30	20.2
	Inner part	59	2	20.1	-18.6	20.3	-7.2

Table E.4.5 Color data for "1% sodium bisulfite treated" artichoke hearts, 2nd half.

$T_{db} = 25°C$. $T_{wb} = 15°C$.

		L	a	b	ΔL	ΔE	ΔBI
25ºC 1% $NaHSO_3$ 2nd half	Outer part	45.9	10.4	15.7	-33.4	35.7	19
	Inner part	54.9	12.8	11.5	-22.7	29.6	-10