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REVIEW PAPER

Osmo-dehydration of Plums and Berries - A Review

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ABSTRACT

The influence of different osmotic dehydration methods on morphological and nutritional attributes of plums and berries has been reviewed and presented in this review. Several researches have been done for retention of bioactive compounds varying osmotic conventionally drying solution, brix, critical moisture content, drying temperature, drying time and methodology of osmotic dehydration process. Osmotic dehydration is a counter flow process which results in solids gain or impregnation, enhancing the textural and rheological properties of plum and related fruits. Osmotically dehydrated plums require less drying time than which results into improved overall quality. Reviews suggested that various osmotic agents with low molecular weight lead to higher water loss. Osmotic dehydration improves the overall quality of plums and berries as compared to the conventional drying methods.

Keywords: Drying, osmotic dehydration, osmotic agent, antioxidants, phenolic compounds, plum, bessy, bioactive compounds

Plums are one of the most important stone fruits crops of the world. Prunes include several familiar stone fruits- apricot, cherry and peach. There are more than 2000 varieties of plums, among which relatively few are of commercial importance (Somogai *et al.,* 2005). These are grown in temperate zone in which China, Romania and U.S.A are the leading countries of world for production of plums (Blazek, 2007). Plums are consumed fresh as well as precessed. The processing includes preparation of beverages both alcoholic and non-alcoholic, canning of plums and drying. As the quality and nutrients of the processed products including dries products are adversely affected by the processing method, the choice of light method is required. The purpose of this paper is to review the effect of different osmotic dehydration methods on nutritional and antioxidant properties of plums and related varieties.

HISTORICAL BACKGROUND

With many known varieties of plums, it is not surprising that it has different heritages and places of origin all over the world. The practice of cultivation has been done since prehistoric times, longer perhaps than any other kind of fruit except the apple. Earliest known data of plums reveal that the plums have origin of China, 470 BC. The European plums are thought to have been discovered around two thousand years ago, originating in the area near the Eastern Europe or

Western Asia (Cambrink and Joshi, 1995). In ancient Roman times, 300 varieties of European plums were mentioned. The pilgrims introduced the European plums to United States in 17th century. Japanese plums actually originated in China rather than Japan. It was introduced to Japan 200-400 years ago (Bhutani and Joshi, 1995), from which it disseminated around the world. Plums may have been one of the first fruits domesticated by humans (Janick, 1998). Plum remains have been found in Neolithic age archaeological sites along with olives, grapes and figs (Janick, 2005; Spangenberg *et al.,* 2006). Today plum is cultivated in all the temperate climate countries of the world. Europe first bred European plum (*Prunusdomestica)*, America first had the American plum (*Prunus americana)*, South Asia cultivated the cherry plum (*Prunuscerasifera)*, and Western Asia is having the Damson plum (*Prunussalicina)*.

Characteristics of Plums

Plums are a drupe fruit of the subgenus *Prunus* of the genus *Prunus*. Weinberger, (1975) reported nearly 2000 species in genus prunus. They come in a wide variety of size and colors like yellow, white, green or red flesh (Koocheki *et al.,* 2010). Mature plum fruit may have a dusty-white coating that gives them a glaucous appearance.

Scientific classification of Plums

Kingdom	Plantae
Order	Rosales
Family	Rosacease
Subfamily	Amygdaloideae (Potter *et al.,* 2007)
Genus	Prunus
Subgenus	Prunus

Composition of plums

Plums are important source of compounds influencing human health and preventing the occurrence of many diseases (Stacewicz *et al.,* 2001). Plums have abundance of bioactive compounds such as phenolic acids, anthocyanins, carotenoids, minerals and pectins. For many decades plums have been used in Indian medicine as a component of natural drugs used in case of leucorrhea, irregular menstruation and miscarriage (Kayano *et al.,* 2003). Nutrients present in plum determine nutritive value and taste of plums (Ertekina *et al.,* 2006).

Antioxidant and Total Phenolic Property of Plum

The plums have great richness of health promoting components like antioxidants and phenolic (Cao *et al.,* 1997; Nakatani *et al.,* 2000; Auger *et al.,* 2004). Predominant phenolic compounds in plums are caffeic acid and its derivatives (Nakatani *et al.,* 2000). According to literature data, depending on the variety, environmental conditions and used analytical methods, phenolic acids content in plums fall within a wide range of values (Table 1).

Table 1: Phenolic components present in plums

Acids	Quantity (mg/kg)
Neochlorogenic acid	85-1300 mg/kg
Chlorogenic acid	13-430 mg/kg
Cryptochlorogenic acid	956 mg/kg

Sources: Donovan *et al.,* 1998; Los *et al.,* 2000; Nakatani *et al.,* 2000; Tomas *et al.,* 2001; Kayano *et al.,* 2002.

These are mostly consumed fresh all over the world.

PROCESSING OF PLUMS

The processing of plum is generally relies on drying of fresh plum, canning and beverage preparation. Although sun drying was very common earlier, today plums are mostly dehydrated (Bhutani and Joshi, 1995). Plums have high sugar content, so to maintain the nutritional and sensory quality, dehydration to desired moisture content, sub-atmospheric conditions are desirable. Different conventional and novel drying techniques are applied for drying of plums such as hot air drying, sun drying, vacuum drying, microwave drying, high pressure assisted drying and osmotic dehydration. Drying of plums is usually done for attainment of low microbial loads and to make more stable product to provide stability throughout the year.

Increased competition in today's global market demands avenues to improve the process efficiency and desirable product quality. So, for increased globalization and consumer awareness it is necessary to minimize the detrimental effects such as physical and chemical changes occurring during processing of plums. In traditional air drying process plums undergo oxidative damage, browning, loss of flavour and shrinkage, which lead to lower sensory and nutritional quality of the products (Aguilera *et al.,* 1997). To improve the product quality and reduce drying time, osmotic dehydration can be an advantageous method for plum drying. It is a pre-treatment for fruits and vegetables prior to drying (Torreggiani, 1993; Torreggiani *et al.,* 2004; Heredia *et al.,* 2007) and other heat assisted processing like canning, freezing, and minimal processing as osmotic dehydration does not lowers the product moisture (Brennan, 1994). As plums are very vulnerable of processing, one should take care of processing parameters best suited for plums.

From the data (Table 1) it can be concluded that phenolic acid content in plums are higher than grapes, kiwi, apples, pears, melons, bananas, while in dried form it exhibits antioxidant capacity higher than that of black currants, blueberries, strawberries, etc. (Wang *et al.,* 1996; Kayano *et al.,* 2002).

Health-Promoting Properties of Plums

Numerous studies confirmed the health-promoting action of plums as a dietary component. Followings are summarized some of the health benefits of plums (1, 2).

Health Benefits

- Regulates the functioning of the digestive system and thereby relieve constipation conditions due to the presence of dietary fiber, sorbitol, and isatin.
- Vitamin C helps the body to develop resistance to infectious agents and scavenges harmful free radicals.
- Fresh plums, like yellow Mirabelle have moderate vitamin A and beta carotene content. Natural fruit's vitamin A protect from lung and oral cancer.
- Plums have significant amount of health promoting flavonoid such as lutein, cryptoxanthin and zeaxanthin. These compounds are one kind of scavengers against aging and disease causing oxygen-derived free radicals and reactive oxygen species. Zeaxanthin provide antioxidant and protective UV light-filtering functions.
- Plums are rich source of potassium, fluoride and iron. Potassium as a important component of cell and body fluids, helps in controlling heart rate and blood pressure.
- In addition, the plums are moderate sources of vitamin B-complex groups such as niacin, vitamin B-6 and pantothenic acid which help the body metabolize proteins, carbohydrates and fats.
- Plums also provide about 5% RDA levels of vitamin K. Vitamin K is important for clotting factors function in the blood as well as in bone metabolism and help reduce the Alzheimer's disease in the elderly.
- Consumption of plums prevents macular degeneration, heart diseases and also damage to our neurons and fats that form a part of our cell membranes.

DRYING OF PLUMS

There is an old saying that "All dried plums are prunes but not all plums are prunes". Plums with high sugar content and firm flesh are dried without removal of stone and are called prunes (Bhutani and Joshi, 1995). Plums are being processed into different kind of products and are used increasingly as food ingredients. Some of the products are dried prunes, prune juice, prune juice concentrate, canned prunes, plum juice, plum paste, prune powder, prune fibre, low moisture prune granules, low moisture prune bits, jam and jelly, fresh-cut plums.

Prunes

Prunes are the dried fruits of some plums cultivar *Prunus domestica L.* that originated from the Caucasus region in Western Asia (Kayano *et al.,* 2003). Frenchmen Louis Pellier introduced the *La Petite d'Agen* prune in 1856, a native of southwest France, to the Santa Clara Valley of California. Today modern dehydrators are being used in place of the old methods of drying prunes in the sun in the United States (Somogyi, 1996). Long tunnels are normally used as dehydrator. Fruits are dried upto 18% moisture, which have sufficiently low-water activity to avoid problems of microbial spoilage and allowing long term storage (Newman *et al.,* 1996). Normally forced-draft tunnel dehydrators are used for drying purposes, which take about 24-36 h drying time, depending upon the size and soluble solids content of the prunes.

Vacuum shelf-drier is conventionally used for drying of prunes to very low moisture content. Final moisture content of dried plums is less than 4% moisture. Prunes have become popular in recent years as wholesome snack with high nutritive and dietary value.

It is believed in marketing that the term 'dried plum' has a more positive image to customers than 'dried prunes' (Somogyi, 1996). In a study dried plums scored higher on the following perceptions of healthiness compared to dried fruits: more natural, easier to digest, containing more vitamins, and eaten instead of candy. Out of all processing about one-half of the plums are consumed fresh. Therefore, different drying techniques are adopted for drying of plums out of which osmotic dehydration not only reduces moisture content for shelf-stable product but also contributes to the sensory quality of the product.

OSMOTIC DEHYDRATION

To satisfy the growing market demand for commodities in a fresh like state, active research is being done in the area of minimal processing such as osmotic dehydration (Phisut, 2012). In recent years, osmotic dehydration process (OD) has been considered an important tool for conservation of tropical fruits and development of new fruit products (Vieira *et al.,* 2012).

Principle and Process

Osmotic dehydration (OD) is an innovative process for drying and preservation of fruits & vegetable in the form of pieces, slices, whole fruit and chunk. It is the mild temperature treatment, also called a "dewatering impregnation soaking process" (DISP), applied to fruits and vegetables in order to partially remove water from their tissues (through semi-permeable membrane) and obtain high quality intermediate moisture foods (Hilaire *et al.,* 2011). Water can be removed partially by dipping the plums in hypertonic solution (salt or sugar or in a combined solution), which also consequently increases soluble solid content. Solute concentration, temperature and contact time are the most influencing operating conditions in OD (Telis *et al.,* 2002).

Osmosis is the movement of water molecules through a selectively-permeable membrane down a water potential gradient or from low solute concentration to high concentration (Rastogi *et al.,* 2002). During osmotic dehydration, cells placed in a hypertonic solution (osmotic pressure higher than that of the cell) will lose water. As the cell wall is permeable, the volume between the cell wall and plasmalemma is filled with the hypertonic solution (Lewicki *et al.,* 2006). In case of perfectly semi-permeable cells membrane, the solute is unable to transfer through the membrane into the cells. But, it is difficult to obtain a perfect semi-permeable membrane in food material because of their complex internal structure and possible damage during processing.

Two major simultaneous counter-current flows occur during osmotic dehydration:

1. Water flow from inside of the samples into the osmotic solution.
2. Osmotic agent diffusion into the opposite direction, which is flowing from solution into the product (Madamba, 2003).

The third flow not much of consideration wherein substances such as vitamins, organic acids, saccharides and mineral salts which flow from food into the osmotic solution. Although, this third flowdoesnt not the mass exchange, to greater extent it can influence the final nutritive values and organoleptic properties of food (Lazarides, 2001; Khin *et al.,* 2005).

The mass transfer process of each component in the solid–liquid system is affected by the operational parameters and by the presence of other components (Shi and Xue, 2009). Osmotic dehydration as a pre-treatment has also a potential for industrial application as it minimizes sensorial and chemical changes due to thermal drying (Krokida *et al.*, 2001; Cao *et al.*, 2006; Torreggiani, 1993). Due to partial removal of water in this process, it reduces packaging, distribution cost and also energy required for moisture removal (Torreggiani, 1993; Panagiotou *et al.*, 1999, Madamba *et al.*, 2002). This method utilizes hypertonic solution hence it eliminates the need of chemical treatment for product stability during storage.

Solid gain such as sugar uptake modifies the sugar-to-acid ratio and the taste of the final product. This may improve stability of pigments during dehydration and attractive texture of several RTE (Ready-to-Eat) products (Raoult *et al.*, 1994; Nahimanai *et al.*, 2011; Phisut *et al.*, 2012).

Sucrose has been recommended for osmotic dehydration of fruits because of its effectiveness, convenience and desired flavor (Lenart, 1996). Shrinkage, decreases water holding capacity, changes in porosity and resistance to deformation is usually observed during osmotic dehydration (Koocheki1 *et al.*, 2010). Moderate temperatures can enhance the retention of natural colour without the addition of sulphites and natural volatile flavour compounds during subsequent drying (Torreggiani *et al.*, 2004). Excessive uptake of sucrose is unacceptable. Textural properties are also influenced by the osmotic treatment leading to increased plasticity of the structure (Krokida *et al.*, 2000). Osmo-dehydrated fruits can then be frozen or dried to further reduce the final moisture content or processed into derivatives to be used in complex food formulations.

OSMOTIC DEHYDRATION OF PLUM AND BERRIES

Only few studies deal with the effects of dehydration treatments on the antioxidant components and antioxidant activity of the processed berries, (Giovanelli *et al.*, 2013). Some researchers have tried to increase the rate of osmotic mass transfer to reduce the processing time (El-Aouar *et al.*, 2006; Moreira *et al.*, 2007; Ispir *et al.*, 2009; Devic *et al.*, 2010; Bchir *et al.*, 2011; Mundada *et al.*, 2011). Some researches held to minimize the uptake of osmotic solids, because it can severely alter organoleptic and nutritional characteristics like the loss of vitamins and minerals salts of the products (Jalaee *et al.*, 2010). Nowadays studies have focused on rapid and effective removal of desired amount of water from food materials such as fruits by adjustment some factors or the operation parameters (El-Aouar *et al.*,2006; Moreira *et al.*, 2007; Devic *et al.*, 2010; Bchir *et al.*, 2011; Mundada *et al.*, 2011).

It has been also proved that there was a statistically significant effect of osmotic dehydration on the compression force required to obtain 25% deformation of dried material.

Doymaz (2004) studied the effect of dipping treatment on air-drying of plums and observed that dipping of plums in 5% potassium carbonate and 2% ethyl oleate for 1 min was effective in removing the natural wax coating and hence, reduced the drying time by about 30% as compared to the untreated samples.

Cinquanta *et al.* (2002) reported that physical (abrasion) and chemical (alkaline ethyl oleate dip) pre-treatments before drying significantly reduced the losses of total phenols. Gabas *et al.* (2002) reported that the rheological properties of prune is a function of drying conditions. The prunes were more pronounced elastic at low moisture content and temperature. Higher moisture contents and temperature lead in more viscous and less-rigid prunes. Del *et al.* (2004) reported that drying had detrimental effect on anthocyanins and ascorbic acid contents. Also showed that drying at 85°C doubled the antioxidant activity in plum cultivar, they studied.

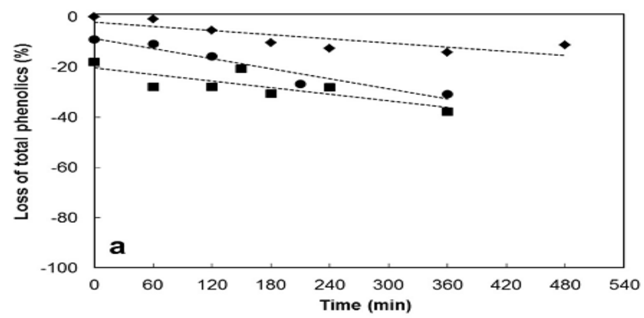
Similarly, osmotically dried prunes were found to be excellent in physicochemical characteristics and sensory quality (Vaidya, 1992). Degradation of di-hydoxycinnamic acid was directly related to evaluation of polyphenol oxidase activity during dehydration and the degradation was high when temperature was low; the reverse was however true with flavanoids (Raynal *et al.*, 1989). However, in change in resulted during the initial hours of drying only. To achieve the desired final moisture content, air-drying is often combined with osmotic dehydration (Brennan, 1994). Osmotic dehydration as a pre-treatment can result in air-dried tomatoes with better color attributes and reduced shrinkage (Pani *et al.,* 2008). Drying kinetics are also effected by osmotic dehydration.

Simultaneous application of osmotic dehydration under high hydrostatic pressure conditions of strawberries was studied with the purpose of analysing the effect of the combined process on the antioxidant capacity, phenolic compounds, colour and vitamin C of strawberries during refrigerated storage. The osmotic solution was prepared using commercial sugar with 40°Brix concentration. Pressurization of samples were done between 100 and 500 MPa for 10 min. Higher antioxidant activity was show at 400 MPa rather than at low pressure (100, 200 and 300 MPa). The total phenolic content increased with pressure, presenting a maximum at 400 MPa, also retention of vitamin C content was observed. Results showed that working at 400 MPa for 10 min ensures physico-chemical and high levels of nutritional contents in osmo-dried strawberries (Yissleen *et al.*, 2013).

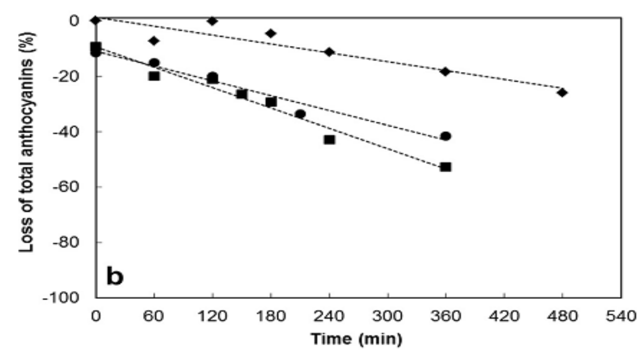
Lohachoompol *et al.* (2004) studied the effects of sugar infusion and drying on the anthocyanin content and antioxidant activity of *Vaccinium corymbosum:* infused dried berries showed a slightly higher loss in anthocyanin content as compared to the untreated dried ones, whereas antioxidant activity was observed with no difference between untreated and infused dried blueberries. In a further study (Yang *et al.*, 1987), *V. angustifolium* blue berries were osmotic dehydrated with solid sucrose prior to freeze drying to obtain a raisin-type blueberry product having good flavour, texture and good shelf stability. A few authors have investigated the dehydration techniques on blue berries but didn't take into account of antioxidant components (Kim *et al.*, 1987; Gregor, 2005; Yang *et al.*, 1987).

Other authors studied the effect of osmotic dehydration and high temperature fluidized bed drying on the drying kinetics and quality characteristics of rabbit eye blueberries (Vaccinium ashei) (Kim *et al.*, 1987). Due to osmotic treatment, the rate of drying was reduced but it prevented shrinking of blueberries and produced dehydrated berries that were less tough as compared to conventional method.

(a)



(b)



(c)

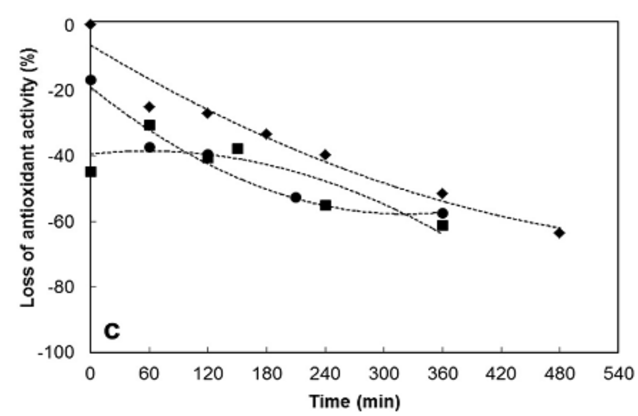


Fig. 1: Percentage loss of total phenolic s (a), total anthocyanins (b) and antioxidant activity (c) during air drying of untreated (A) blueberries and of blueberries osmo-dehydrated in sucrose (-) and glucose/fructose (C) solutions (average results of two replicated trials).

The blanched blueberries were dipped in 60°Brix sucrose and 48.6°Brix fructose/glucose osmotic solution for 24h and were subsequently, air dried at 70°C to final moisture content of 10-14%. Data show that the osmotic treatment causes significant losses in the antioxidant components (total phenolics, total and individual anthocyanins) and in the antioxidant activity. Drying also caused losses in the antioxidant components. Glucose/fructose infusion gives better results in terms of morphological changes, with lower shrinkage and wrinkling of the berries (Giovanelli *et al.,* 2013). Effects can be seen in Fig. 1.

Giovanelli *et al.* (2012), studied the effect of a steam blanching preconditioning step on the chemical, nutraceutical and morphological characteristics of osmo-dehydrated blueberries (*Vaccinium corymbosum* L.) in sucrose or glucose/fructose osmotic solutions. Blanching caused increased mass transfer during osmotic dehydration but reduced the loss of phenolic compounds with an improvement in retention of antioxidant components. Their color was also deeper.

Kim *et al.* (2003) studied the dehydration of plum (*Prunus salicina* L.) slices with red algae extract (RAE) at a concentration of 30% (w/w). The rehydration ratios and colors of RAE treated plum slices were better than those of MD-treated and hot-air dried samples. The ascorbic acid content was good and microstructures were finer as compared to other treatment. Oxidation damage could be minimized by using osmotic dehydration as a pre-treatment to air-drying (Heredia *et al.,* 2007; Lewicki *et al.,* 2002).

Phisut *et al.* (2013) determined the effect of osmotic dehydration process (fast osmotic dehydration: (FOD) and slow osmotic dehydration: (SOD) on the physical, chemical and sensory properties of osmo-dried cantaloupe. The results showed that there is no difference beween color but SOD resulted in softer texture and lower vitamin C, phenolic compound and antioxidant quality.

Agnieszka *et al.* (2010), investigated the influence of osmotic dehydration and type of osmotic solution on selected physical properties of freeze-dried strawberries (Fig. 2). It was also proved that there was a statistically significant effect of osmotic dehydration on the compression force required to obtain 25% deformation of dried material. Freeze-dried strawberries showed a decreasing pattern in rehydration capacity and adsorption rate that were

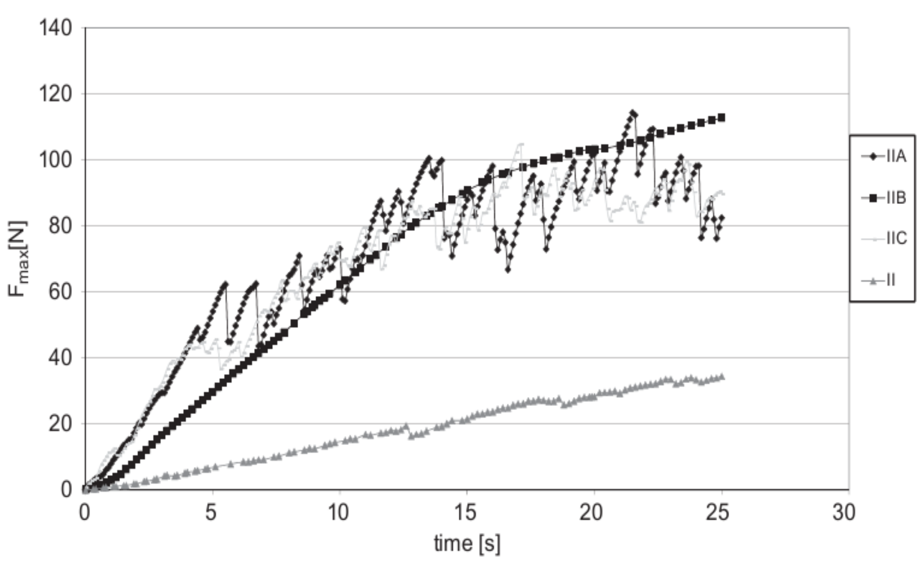


Fig. 2: Influence of osmotic dehydration and type of osmotic solution on mechanical properties (compression test) of osmotically dehydrated freeze-dried strawberries. Type of osmotic solution: IIA: sucrose; IIB: glucose; IIC –: starch syrup; and II: without osmotic dehydration. F: compression force necessary for 25% deformation of dried material.

osmotically dehydrated in sucrose and glucose solution. Osmotic dehydration in glucose solution resulted in flatter sorption isotherms than osmotic dehydration in sucrose and starch syrup solution.

CONCLUSION

The stability of various nutritional and functional quality parameters of plums is dependent on drying time, drying temperature and critical moisture content of the product. It directly influences the antioxidants and phenolic compounds of plums and other berries. Water activity of osmotic solution and osmotic treatment process are the important factors for textural properties of the products. Reduced geometry favored reduction in oxidative damage while mechanically bruised fruits at higher drying temperature resulted in less rigid product. Hence, it can be concluded osmotic pre-treatment combinations are based on different drying methods implied for drying of berries.

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