IJFANS
International Journal of Food And Nutritional Sciences

Volume 3 Issue 3 Apr-Jun-2014, www.ijfans.com e-ISSN: 2320-7876

INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES

Official Journal of IIFANS

INTERNATIONAL JOURNAL OF FOOD AND NUTRITIONAL SCIENCES

e-ISSN 2320 –7876 *www.ijfans.com*
Vol.3, Iss.3, Apr-Jun 2014

Research Paper *Open Access*

OSMOTIC DEHYDRATION OF FRUITS – AN INTEGRATED APPROACH

Josephine Selvi.N[1*], Aruna Singh[2] and Baskar.G[3]
[1]Department. of Chemical Engineering, Sathyabama University, Chennai, [2]Department of Biotechnology St. Joseph College of Engineering, Chennai, [3]Department of Chemical Engineering Vellore Institute of Technology, Vellore.

[*]Corresponding Author. njoe14@gmail.com

ABSTRACT

The objective of this paper is to investigate the integrated approach of Osmotic Dehydration of fruits. Here mass transfer in osmotic dehydration process, modeling of the process, design of osmotic dehydration, various equipment used for osmotic dehydration, rehydration of the product, ways of using spent osmotic solution, various predehydration techniques for the development of good quality of products and energy saving has been covered. Finally use of RSM technique for optimization of process parameters has been explained. Osmotic dehydration is more than a preservation technique because of the superior quality of the finished product. Water removal in this process is carried out without phase change. The process is achieved by direct contact of fruits with a hypertonic solution. The driving force for water removal is the difference in the concentration of solute inside the cell and osmotic solution. The cell wall and membrane acts as the semi permeable membrane. During osmotic dehydration 3 mass transfer operations are observed. 1. Movement of water from fruit cell to the hypertonic solution. 2. Movement of osmoactive substance from hypertonic solution into the cell and 3. Elution of own solutes from the cell to the Osmotic solution.

Keywords: Osmotic dehydration, RSM, hypertonic solution, Solid gain, water loss, Weight reduction.

INTRODUCTION

Fruits were important source of vitamins and minerals along with dietary fiber. They contain nearly 75% of moisture because of which they get rotten, affected by fungi, moulds etc., before reaching the consumption point (Janisiewicz, 1999). Osmotic dehydration was one of the most important dehydration and pretreatment method and hence a popular preservation technique (Alakali, 2006) that reduces moisture content up to 30 – 50% (Rastogi, 1997) it reduces the heat damage to texture, color and flavor of the finished product.Osmotic Dehydration (OD) was effective at ambient temperature (Torres et.al., 2006). Also heat removal here takes place without phase change, which was the primary attraction of OD. Since the latent heat of water vapor was high, heat required to evaporate water was high. The finished products surface and structural effects are comparatively good and acceptable (Torreggiani, 2001).

In spite of the good quality of the finished products and energy advantage of OD, it alone cannot produce a product with stability and longer shelf life. It should be used in combination with freeze, vacuum, microwave or air drying. Also disposal of osmotic solution was major issue, which can be sorted out by recrystallisation and reuse or could be used as raw material for other fruit based products. But if the osmotic solution basically contains NaCl then good treatment and disposal techniques should be in place (Piotr et.al., 1988). The equipments used for the same should be carefully chosen based on the end product. Never the less selection of solution to sample ratio and optimization of process parameters was essential for the economic operation. To carefully handle the above issue a good knowledge of the underlying mass transfer operation was must.

MASS TRANSFER

During the process of Osmotic dehydration Simultaneouscounter-current flows may occur; water flow out of the fruits into the hypertonic solution, the simultaneous transfer of osmoactive solutes from the solution into the fruits, and migration of own solutes like sugars, organic acids, vitamins,reducing sugars, some flavor compounds, volatiles, minerals, etc., from the food into the solution (Le Maruer, 1988).Since the hypertonic solution has reduced wateractivity with higherosmotic pressure, it serves as a driving force forwater removal from the cellsto the osmotic solution. Even though theremoval of water from fruit cell during osmoticprocess is mainly by diffusion and capillary flow, the solute uptake or leaching was only by diffusion (Rahman, 2007). All these mass exchangesbetween the osmotic solution andfoodstuff may have an effect on theoverall yield and quality of thedehydrated product.

Inplants tissue due to the presence of semi-permeable membraneand because of the low molecular size ofwater molecules the flux of water coming out of the fruits was much largerthan solute gain from osmoactive substance. This explains the fact when both water loss and solid gain takes place in parallel mode; water loss was more compared to the solid gain. Also it results in a decrease ofwater content of the product with time, till equilibrium condition was established.Therefore, the weight of the foodstuffwill decrease, as well the water activity. According to some works, it was reportedthat up to 50% reduction in the freshweight of fruits or vegetables can beachieved by osmotic dehydration (Rastogi, 1997).

PROCESS MODELING AND KINETICS

The characteristics of Osmotic dehydration were studied using the response variables weight reduction (WR), water loss (WL) and solids gain (SG). The initial and final moisture content was determined using hot air oven method recommended by Ranganna, 2001.

$WR = (M_o - M)/M_o$ -- (1)

The moisture loss was measured by the following equation suggested by [10, 11]

$WL = WR + SG$ -- (2)

The solid was measured by the following equation suggested by (Lenart, 1984 and Hawkes, 1978)

$SG = (m - m_o)/M_o$ -- (3)

Where M_o - initial mass of sample (g), M - mass of sample after dehydration (g), m_o – initial mass of the solids in sample (g), m - mass of the solids in sample after dehydration (g).Also the following drying models were used to study the drying kinetics.

Lewis model: $M.R = exp(-kt)$ --------------------------- (4)

Henderson model: $M.R = a\, exp(-kt)$ ------------------ (5)

Logarithmic model: $M.R = a\, exp(-kt) + c$ ------------- (6)

Parabolic model: $M.R = a + bt + ct^2$ ----------------------- (7)

Where M.R was moisture loss ratio = $(M-M_e)/(M_o-M_e)$, where M_o, initial moisture content, M, moisture content after time t, M_e, the equilibrium moisture content, t, the time period, and a,b,c and k are constants. Effective diffusivity was found out using the method of slope.

$M.R = 8/\pi^2 exp(-\pi^2)\, D_{eff}\, t / 4L^2)$ --------------------------- (8)

Where D_{eff}, effective diffusivity, t time and L length.

DESIGN OF OSMOTIC DEHYDRATION

In the process of osmotic dehydration selection of hypertonic solution was important. It affects the solute uptake, water removal, sensory and physical properties of the final finished product. Cost of osmotic solution, ability of the solutes in relation with the components of the osmosedmaterial (Pan *et.al.,* 2003), to get good rate of processing were to be considered in selection of the osmotic solution. Any edible solute dissolved in water can be used for the purpose. Solution to sample ratio should also be chosen wisely so that the driving force for the removal of the moisture exists till the end of the process.

Compared to sugar, infusion of NaCl was more. Also when NaCl alone was used taste of final product becomes undesirably salty (Lerici et.al., 1985). So sugar has beenreported as excellent osmotic agent that has benefits like inhibitor of polyphenoxidase, also inhibits oxidative browning, protects the essential volatile compounds, that helps to restore the sensory properties of original food material (Ponting, 1973), contributes stability of pigments and excellent retention of volatile compounds during drying of osmotically treated materials (Ferrando, 2001). A combinationof solutes was used to check the properties of materials.It had been reported that adding a small quantity ofsodium chloride to the solution of sugar boosted up theosmotic drying force due to its lower molecular weightand higher capacity of decreasing the water activity (Lerici et.al., 1985, Taiwo, 2003 and Azouble et.al., 2002). Also use of corn syrup, fructose, maltodextrin, binary solution and ternary solutions were reported in the literature (Ali et.al., 2010 and Raji et.al., 2010).

EQUIPMENT USED FOR OSMOTIC DEHYDRATION

Equipment for Osmotic dehydration was classified by Marouze´ *et al* (2001) based on the following category. 1. Those in which food was immersed in the solution. 2. Those in which solution was introduced onto the food 3.Those in which osmotic substance in solid state was contacted with food and4. Those in which reduced pressure was used to facilitate mass transfer.

In the first category the fruits are put in a basket and immersed in an osmotic solution. Convective mass transfer is predominant in this case. Most of the Process parameters are not controlled. The resistance to mass transfer can be reduced by slow movement of the fruits or circulation of the solution. The fruits may be moved in a conveyor or it can be vibrated (Smarkusz, et.al., 1998). However due to the mechanical movement, disintegration or deformation of the product may be observed. Also pulp content in the hypertonic solution may increase. When the solution to sample ratio used should be less, then the second category of equipments can be adopted. The samples can be placed on a perforated plate and the hypertonic solution can be sprayed on the surface. This was well suited for continuous process but requires more space for processing the given quantity. This technique is proposed by Dalla Rosa et al and Le Maguer (1988).

In the third category the sample and the solid osmotic substance were mixed in appropriate proportion and tumbled inside the cylindrical vessels. Lowest solution to sample ratio was achieved in this technique. After completion of the process the moisture removed from the fruit sample will wet the sugar or sugar and salt mixture. Then the osmotic agents were removed from the surface of the sample by vibrating them on a screen (Piotr et.al., 1988). The problem encountered here was some crystals may stick on to the fruit surface which may interfere in the further processing. In the last category the osmotic dewatering is carried out under static or pulsed vacuum processing technique. The equipmentdiagram for the above cases can be found elsewhere in the literature.

PRODUCT REHYDRATION

Product rehydration was also equally important. The extent of rehydration gives the information about the extent of freshness of the product. Rehydration was carried out at two different temperatures by dipping the samples in the distilled water at different temperature (Taiwo et.al., 2003). The samples were removed from the beakerat stipulated intervals, adhering water was carefully blotted out using tissue and weighed accordingly. After rehydration, the sampleswere dried in the air oven at 60°C for 27 hr to determine the solidcontent.Rehydration at lower temperatures seems to promote fasterwater diffusion into the product through swelling and plasticizing of membranes (Oliveira, 1999).

CHARACTERISTICS OF OSMOTIC DEHYDRATED FRUITS

The Osmotic dehydration was a complex counter current mass transfer process. Due to this mass transfer between the cell and the osmotic solution, along with dehydration, changes in chemical composition are also expected (Ziegler, 1975, Philip, 1958 and Witrowa et.al., 1996). The flux of osmo active substances penetrate the osmosed tissue to change its chemical composition hence osmo dried material was different than that of the convective dried product. The sucrose flux was increased by the presence of sodium chloride but starch syrup gives rise to small infusion of the sucrose. Glucose proves more effective in both water loss and in solid gain compared to the glucose. Flux of native substance from the tissue lowers the organic acids and the native sugar of the fruits and was replaced by the sugar (Dixon et.al, 1976 and Lerici et.al., 1977). Never the less there was a good surface finish and structural finish of the final products when compared to convective air drying.

SPENT OSMOTIC SOLUTION

The spent osmotic dehydration solution can be recycled for further use as osmotic agent. Possibility of reusing the osmotic solution for nearly 20 times is reported in the literature (Piotr et.al., 1988). After reusing at one point of time it has to be disposed. The various methods of further use or disposal are 1.Bee feeding 2. Jam preparation 3. Candy preparation 4.Fruit flavored drink. 5. Syrup for fruit canning 6.production of natural flavorings 7.Mixing with fruit juices

If the processing was done with only Sodium chloride, the management of the spent liquor was very difficult, a solution to which was the need of the hour. Usually vegetables are dehydrated using sodium hydroxide. Presence of high organic content and carbohydratescalls for higher BOD. Efficient waste water disposal system should be in place (Piotr et.al., 1988).

PREDEHYDRATION TECHNIQUE

Fruits contain nearly 75% of moisture content. Osmotic dehydration removes 30-50% of moisture present in the fruits. But the problem lies in the preparation of the fruit skin.Pre-treatment conditions before osmoticdehydration process affect productinherent integrity which has an effect onmass transfer process. Osmoticdehydration rate was largely affected by cell membrane permeability (Yetenayet, 2010).

The outer tissueof the fruits has very low permeability forwater and solutes; hence the skin must be removedbefore osmotic treatment. In the case of small fruits like grapes, berries the skin permeability can be increased. For this purpose NaOH solution containing ethyl oleate can be used. It proved to be effective for tomato (Shi et.al., 1997) and strawberries (Venkatachalapathy, 1999).

Most of the fruits and vegetables were cut into piecesbefore they were contacted with hypertonic solution.Shape and size of the material do affectthe rate of the dehydration process. Based on the consumer requirement and the technology used the osmosed fruits assumes various forms (Lenart et.al., 1998). Plums were cut into whole or in halves (Camirand et.al., 1968) apples were dehydrated as 12 segments (Ponting, 1973) or sliced into 3-mm slices (Dixon et.al., 1976). Peaches were cut into 6 or 8segments and pears into 8 segments (Ponting, 1973). Papayas were cut into cubes. Lenart and Lewicki have shown that the thicknessof the material should not exceed 10 mm (Lenart et.al., 1980 and Lenart, 1996).Taking into account further processing following osmoticdehydration and use of the product, they considereda cube with a side dimension close to 10 mmas an optimal size and shape for most materials.

ENERGY SAVING

The osmoticdehydration step can be added, anywherealong theconventional drying process, before, after or even along with it, toenhance the mass transfer rate or to shorten the duration of drying time.After the osmotictreatment, the moisture content of fruits and vegetables were usually reduced by 30-50% (wet basis). However osmotic dehydration alone cannot provide longer shelf life and stability to the final product. Hence osmotic dehydration was used in combination with freeze, convective, microwave or vacuum drying steps. This provides 2 advantages from conservation of energy point of view. Firstly reduction in moisture content to an extent of 50% [3]which means drying load on the successive step wasreduced, Secondly moisture removed was in liquid form without phase change.This was another major reason for energy saving, (Lazarides et.al., 1994) since the latent heat of water vapor was more, the heat required to evaporate water was also more.

Quality advantage of osmotic dehydration was 1. Minimum damage to the cell, as the operation was carried out at low temperatures (Lazarides et.al., 1994). 2. Enzymatic browning was reduced since the fruits were immersed in the hypertonic solution (Dixon, 1976), because of which the need for antioxidants was also avoided.

RSM TECHNIQUE FOR PROCESS PARAMETER OPTIMIZATION

Transfer of mass in osmotic dehydration was affected by various process parameters like Temperature, time, size and geometry, concentration of osmotic solution, sample to solution ratio, agitation methods of pre dehydrationetc.,. Temperature plays a predominant and important role in breaking the integrity of plant material and membrane. Example the plasma membrane undergoes irreversible damage at 50^{o}C (Thebud, 1982). Increasing the level of agitation increases the mass transfer rate, when the time passes, the membrane did not provide barrier to osmoactive substance (Rastogi, 1997). The solution to sample ratio was yet another factor, the driving force to release the water becomes less when the osmotic solution becomes dilute. If the geometry or size was bigger and thicker then the length of the diffusion path was higher (Rastogi, 1997).

The Response Surface Methodology (RSM) technique was a collection of mathematical and statistical techniques that were useful for modeling and analysis of problems in which output or response was influenced by several input variables and the objective was to find the correlation between the response and thevariables investigated (Montgomery, 2001 and Suresh Babu et.al., 2011). RSM was originally developed for the physical experiments by (Box, 1987) and later, adopted in other fields. RS model was formulated as a polynomial function. Oktema*et al., (*2005) has utilized RSM to create RS model, bydeveloping a computer program written in MATLAB programming language. Box Behnken and Rotational Central Composite Design (RCCD) were two types of RSM available for Experimentation work. Box-Behnken Design was used for non-sequential experiments, i.e., used for the experiments when the experiment set was performed once. A RCCD can be used when a comparatively accurate prediction of all response variable averages related to quantities measured during experimentation.

Using Design Expert software (www.statease.com) RSM can be performed for the optimization of process parameter in osmotic dehydration. Along with optimization RSM wasalso used to find the effect of correlation between the inputs on the response. Here more than one response can be studied. For example relation between temperature, concentration, time, agitation and slice thickness can be studied on the response like solid gain, weight reduction and water loss of the osmotic dehydration process. Checking the contour plot, the extent of relation between the parameters can be found out. If the response plot shows elliptical contour then correlation between the selected two parameters was high. If the contour obtained was in round shape there was no relation between the selected parameters. Other shapes between elliptical and round confirms the relation was low to medium.

REFERENCES

- Janisiewicz, W.J., W.S. Conway and B.Leverentz. Biological control of postharvestdecays of apple can prevent growth of Escherichiacoli O157:H7 in apple wounds. Journal of Food Protection.1999; 62:1372-1375.
- Alakali, J.S., C.C. Ariahu and N.N. Nkpa. Kinetics of osmotic dehydration of mango.Journalof Food Processing and Preservation.2006; 30:597-607.
- Rastogi, NK, Raghavarao, K. Water and solute diffusion coefficients of carrot as a function of temperature andconcentration during osmoticdehydration. Journal of Food Engineering1997; 34:429-440.
- Torres, J.D., P. Talens and I.A Escriche. Chiralt Influence of process conditions onmechanical properties of osmoticallydehydratedmango. Journal of Food Engineering.2006; 74: 240-246.
- Torreggiani, D and G. Bertolo. Osmotic pretreatments in fruit processing: chemical, physicaland structural effects. Journal of Food Engineering.2001; 49:247-53.
- Piotr P. Lewicki and AndrzejLenart.Osmotic Dehydration of Fruits and Vegetables.Handbook of Industrial drying.
- Le Maruer, M and Biswall, CJ. Multicomponent diffusion and vapourliquid equilibria of dilute organiccomponents in aqueous sugarsolutions.American Institute of ChemicalEngineering Journal 1988; 18(3):513-519.
- Rahman, MS, and Perera, CO. Dryingand Food Preservation. pp.412. InRahman MS, Handbook of foodpreservation, 2007; 2nd ed., CRC press.
- Ranganna. S.. Handbook of Analysis and Quality control of fruit and vegetables product, 2001; 3rd (Edn). Tata McGraw-Hill Publ.co.NewDelhi, India.

- Lenart A. &Flink J.M. Osmotic dehydration of potato. I, Criteria for the end point of the osmosis process. J. Food technology, 1984; 19, 65-89
- Hawkes J. &Flink J.M. Osmotic concentration of fruit slices prior to freeze dehydration. J. Food Processing Oreserv., 1978; 2, 265-284.
- Lazarides H.N., Katsanides E. &Nickolaidis A.Mass transfer during osmotic preconcentration aiming at minimal solid uptake.J Food Engg. 1994; 25(151)
- Raoult-Wack A.L., Rios G., Saurel R., Giroux F. &Guilbert S. Modeling of dewatering and impregnation soaking process (osmotic dehydration). Food Research International, 1994; 27(2), 207-209.
- Pan, YK., LJ. Zhao, Y. Zhang, G. Chen and AS.Mujumdar. Osmotic dehydrationpretreatment in drying of fruits and vegetables.Drying Technology.2003; 21: 1101-14.
- Lerici, CR., G. Pinnavaia, M. Dalla Rosa and L.Bartolucci. Osmotic dehydration of fruit:influence of osmotic agents on drying behavior andproduct quality. Journal of Food Science.1985; 50:1217-9.
- J.D. Ponting, Osmotic dehydration of fruits—Recentmodifications and applications, Process.Biochem.,1973; 8:18.
- Ferrando, M and W. Spiess. Cellularresponse of plant tissue during the osmotictreatment with sucrose, maltose and trehalosesolutions.Journal of Food Engineering.2001; 49:115-27.
- Taiwo, K.A., M.N. Eshtiaghi, B.I.O. Ade-Omowaye and D. Knorr. Osmoticdehydration of strawberry halves: influence ofosmotic agents and pretreatment methods on mass transfer and product characteristics. Int. J. of Food Science and Technology.2003; 38: 693-707.
- Azoubel, PM., F. Murr.. Effect ofpretreatment on the drying kinetics of cherry tomatoes (Lycopersiconesculentum var.cerasiforme). In: Welti-Chanes J, Velez-Ruiz JF, eds. Trans. Phen. Food Proc. 1st ed. Boca Raton:CRC Press. 2002; 131-51.
- Ali, H.S., A. Hesham, M.T. Moharram, Ramadanand G. H. Ragab.. Osmotic Dehydration ofBanana Rings and Tomato Halves. Journal ofAmerican Science.2010; 6(9).
- Marouze´, F. Giroux, A. Collignan, and M. Rivier, Equipment design for osmotic treatments, J. FoodEng., 2001; 49:207
- S. Smarkusz, P.P. Lewicki, A. Lenart, and C. Stygar,Urzadzenie do krojeniawarzyw I owoco´w, głowicanozowa do tegourzadzeniaorazno´zkrazkowy do tejgłowicy.Patent 1998; P-329 263.
- S. Smarkusz, J. Kiełkiewicz, W. Raczko, P.P. Lewicki,A. Lenart, and W. Płocharski, Liniaprodukcyjnadowytwarzaniaczipso´w, Patent 1998; P-329 264.
- M. Dalla Rosa, F. Bressa, D. Mastrocola, and P.Pittia, Use of osmotic treatments to improve the qualityof high moisture-minimally processed fruits. InOsmotic Dehydration of Fruits and Vegetables (A.Lenart and P.P. Lewicki, eds.), Warsaw AgriculturalUniversity Press, Warsaw, 1995, p. 69.
- M. Le Maguer, Osmotic dehydration: review and futuredirections. In Prog. Food Preservation Processes,Vol. 1, CERIA, Brussels, 1988, p. 283.
- Oliveira ARF, IlincanuL In ARF Oliveira, JC Oliveira. Processing foods,quality optimization and process assessment. London CRC Press, 1999; pp 201-225.
- H. Ziegler, Nature of transported substances. In Encyclopediaof Plant Physiology, Vol. 2. Transport inPlants I. Phloem Transport (M.H. Zimmermann andJ.A. Milburn, eds.), Springer Verlag, Berlin, 1975; p. 59.
- J.R. Philip, Osmosis and diffusion in tissue: half-time and internal gradients, Plant Physiol., 1958; 33:275
- D. Witrowa-Rajchert, P.P. Lewicki, and A. Lenart,The influence of osmotic pretreatment on dry carrotreconstitution properties. In Proceedings of the 10th International Drying Symposium. Drying'96 (Cz. Strumiłło,Z. Pakowski, and A.S. Mujumdar, eds.), Ło´dzTechnical University, Ło´ dz, vB: 1996, p. 847.
- M. Dixon, J.J. Jen, and V.A. Paynter, Tasty appleslices result from combined osmotic-dehydration andvacuum-drying process, Food Process. Develop.,10:634 (1976).
- R. Lerici, N. Pepe, and G. Pinnavaia, La disidratazionedellafruttamedianteosmosidiretta. I. Resultatidiesperienzeeffettuate in laboratorio, Ind. Conserve.,52:1 (1977).
- Yetenayet Bekele and HosahalliRamaswamy, Going beyond conventional osmotic dehydration forquality advantage and energy savings.EJAST. 2010; 1(1): 1-15
- J.X. Shi, M. Le Maguer, S.L. Wang, and A. Liptay.Application of osmotic treatment in tomato processing—effect of skin treatment on mass transfer in osmotic dehydration of tomatoes, Food Res. Int., 1997; 30:669.
- K. Venkatachalapathy and G.S.V. Raghavan, Combinedosmotic and microwave drying of strawberries,Drying Technol., 1999; 17:837.

- Lenart and R. Da̧browska, Mass transfer duringosmotic dehydration of apples with pectin coatings, InProceedings of the 11th International Drying Symposium, 1998; Drying'98.Akritidis, D. Marinos-Kouris,G.D. Saravacos, and A.S. Mujumdar, eds.), ZITI Editions,Thessaloniki, 1998, p. 903.
- W.M. Camirand, R.R. Forrey, K. Popper, F.P. Boyle,and W.C. Stanley, Dehydration of membrane coatedfoods by osmosis, J. Food Agric. Chem., 1968; 19:472.
- D.F. Farkas and M.E. Lazar, Osmotic dehydration ofapple pieces: effect of temperature and syrup concentrationon rates, Food Technol., 1969; 23:688.
- M. Dixon, J.J. Jen, and V.A. Paynter, Tasty apple slices result from combined osmotic-dehydration andvacuum-drying process, Food Process. Develop.,10:634 (1976).
- Lenart and P.P. Lewicki, Osmotyczneodwadnianiejabłekwcyrkuluja̧cymsyropiecukrowym, Zesz. Probl. Post. NaukRoln., 243:223 (1980).
- Lenart and P.P. Lewicki, Owoceiwarzywautrwalonesposobemosmotyczno-owiewowym, Przem.Spo_z., 1996; 50:70.
- Thebud, R and K.A. Santarius.. Effects ofhigh temperature stress on various biomembranesof leaf cells in situ and in vitro. Plant physiology1982; 70: 200-205.
- Montgomery D. C., 2001. Design and Analysis of Experiments, John wiley and Sons Inc.
- V. Suresh Babu, S. Sriram Kumar, R. V. Murali and M. Madhava Rao, Investigation and validation of optimal cutting parameters for least surfaceroughness in EN24 with response surface method. Int. J of Engineering, Science and Technology. 2011; 3(6): 146 -160
- Box G.E.P., Draper N.R. 1987. Empirical model-building and response surface, John Wiley and Sons, Inc., New York, USA.
- Mason R. L., Gunst R. F, D., Texas, and Hess J. L.. 2003. Statistical design and analysis of experiments with applications toengineering and science. 2nd Edition, John Wiley and Sons Publication.
- Designexpert software: http://www.statease.com/dx8descr.html
- Raji Abdul Ganiy O, Flade Kolwole O, Abimbolu Fadeke W. Effect of sucrose and binary solution on Osmotic dehydration of bell pepper (chilli) (Capsicum spp.) varieties. J Food science Technology 2010; 47(3): 305-309.
- Box G.E.P, Wilson KB.The exploration and exploitation of response surfaces: some general considerations and examples.Biometrics; 1954; 10:16–60.