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Pulsed Vacuum Osmotic Dehydration of Garlic Bulbs followed by Microwave Drying

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ABSTRACT: The combination of pulsed vacuum osmotic dehydration and microwave drying of garlic bulbs were examined. The response surface methodology (RSM) was used to determine the effect of NaCl concentration (8%-20%), osmotic solution temperature (25-65°C), operation pressure (240-830 mbar), immersion time (20-300 min) and microwave power level (100-600 W) on water loss (WL), solids gain (SG), weight reduction (WR), hardness and shrinkage of samples. Analysis of the results showed that by increasing the osmotic solution concentration, temperature and immersion time, WL and WR will increase. The effect on SG was almost the same as WL except the effect of temperature. Increasing temperature resulted in an initial increase in SG for a period of time, followed by a decrease. NaCl concentration, temperature and immersion time showed the significant influence on hardness.

Keywords: *Garlic, Microwave Drying, Pulses Vacuum Osmotic Dehydration, Response Surface Methodology.*

Introduction

Garlic (*Allium sativumL.*), belongs to the *Liliaceae* family, is a common food spice, used widely in many parts of the world. Garlic is a semi-perishable spicy herb, used as a primary ingredient for preparing various kinds of foods. The moisture content of fresh harvested garlic is approximately 162% (dry basis) and the garlic is then dried to maintain its quality for prolonged storage (Ambrose & Sreenarayanan, 1998). Dehydration is an important operation in the food processing industry. The quality of dehydrated products is dominated by drying methods and conditions. Conventional hot-air drying results in extremely shrunken products with tough texture, severe browning, low rehydration rate, and low nutritive value (Huang *et al*., 2009; Krokida & Maroulis, 2000). Moreover, it is energy intensive and consequently cost intensive due to its simultaneous mass and heat transfer process accompanied by phase change (Fernandes & Rodrigues, 2007). Osmotic dehydration is a gentle way of removing water from plant tissues such as fruits or vegetables. Osmotic dehydration is carried out by immersion in a hypertonic solution. The movement of moisture from the product to the osmotic solution is governed by the difference in osmotic pressures. Not only is the moisture removed from the product but diffuse from the hypertonic solution into the product (Lombard *et al*., 2008). More than 50% of the water is taken out with the help of hypertonic solutions. After that, the fruit pieces are very soft and are still subjected to spoilage by a variety of microorganisms.

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The water content needs to be lowered further to gain microbiological stability without cool storage. Osmotic dehydration (OD) and pretreatment prior to drying was found advantageous for improving the product quality and for decreasing energy consumption (Mandala *et al*., 2005; Moreno *et al*., 2004).

Diffusion is the major mass transfer mechanism responsible for water transport, and it is well known that diffusional mechanisms are quite slow. The influence of vacuum treatment on the kinetic of the mass transfer phenomena is very important, especially where concerning water loss and weight reduction (Fito, 1994). Pulsed vacuum osmotic dehydration (PVOD) is a variation of vacuum in osmotic dehydration (VOD), consisting of using a VOD initial process followed by the OD at atmospheric pressure (Tapia *et al*., 1999). During the vacuum step, the internal gas in the product expanded and partially flows out. All this is coupled with the capillary penetration as a function of the interfacial tension of the liquid and the diameter of pores. In the atmospheric step, the residual gas is compressed, and the external liquid flows into the pores as a function of the compression ratio (Fito, 1994). The characteristics of raw material, the process variables (concentration, temperature, time, pressure gradients), and the osmotic agents used, strongly affect the mass transfer phenomena taking place during osmotic dehydration (Nsonzi & Wamy, 1998; Nsonzi, 1997).

Microwave energy is increasingly being used worldwide for the industrial processing of foods. However, in comparison with household appliances, microwave processing in the food industry has not been as successful. The principal reasons for the slow development of microwave energy for industrial processes are related to costs and lack of information about the technology (Schiffmann, 1992; Mudgett, 1986). Use of microwave heating offers many advantages as compared to the conventional heating methods, namely fast operation, energy savings, precise process control, and faster start-up and shutdown operation (Decareau, 1985). Because microwaves penetrate within a food product and do not just act at its surface, energy conversion into heat throughout the product is more efficient. This accelerated heating gives a higher quality product in taste, texture, and nutritional content, as well as increased production (Wang & Sheng, 2006).

Response surface methodology (RSM) is a statistical procedure frequently used for optimization studies. It uses quantitative data from an appropriate experimental design to determine and simultaneously solve multivariable problems. Equations describe the effect of test variables on responses, determine interrelationships among test variables and represent the combined effect of all testvariables in any response. This approach enables an experimenter to make efficient exploration of a process or system (Eren *et al*., 2007). Therefore, RSM has been frequently used in the optimization of food processes (Liyana-Pathirana & Shahidi, 2005; Eren *et al*., 2007; Corzo *et al*., 2007; Wani *et al*., 2008; Changrue, 2008; Shi *et al*., 2008; Altan *et al*., 2008).

The main objectives of this work were to investigate the effect of pulsed vacuum osmotic dehydration on mass transfer and microwave drying behaviour of garlic bulbs.

Materials and Methods

Fresh garlic Bulbs of uniform quality were purchased from local market with a similar size and ripeness. Garlic bulbs were stored at +5°C until used. A few hours prior to the test, the garlic bulbs were left to equilibrate at room temperature. Osmotic solutions were prepared by mixing food grade NaCl with the proper amount of distilled water.

-Osmotic dehydration

The processing parameters and their limits those were determined with pre-examinations, including temperature (25-65ºC), NaCl concentration (8%-20% (w/v)), immersion time (20-300 min), microwave power (100-600 W) and operation pressure (240-830 mbar for 10 min at the start of the experiments). The sample-to-solution ratio was for all experiments1:10(v/w) to avoid significant dilution of the medium by water removal, which would lead to local reduction of the osmotic driving force during the process. The agitation speed of 100 rpm was used and maintained constant.

Garlic bulbs were washed with tape water removing solids and other particles by hands and peeled. Samples were immersed simultaneously into the osmotic solution of a given concentration and temperature. A vacuum pulse according to the experimental design for 10 min was applied, after that; the osmotic dehydration was carried out at atmosphere pressure.

After osmotic pretreatment, the bulbs were removed from the osmotic medium, quickly rinsed with distilled water (ca. 30 s) to remove the solution adhered to the surface of the bulbs, and then blotted with absorbent paper to remove the excess water. Total solid content of the fresh and treated samples was determined. A microwave dryer was used for drying of pre-treated bulbs. Samples were dried until reached the final moisture content.

The moisture content of the samples was determined by standard air oven method (AOAC, 1984). Evaluations of mass exchange between solution and sample during osmotic dehydration were made by using the parameters such as water loss (WL), solid gain (SG) and weight reduction (WR) and were calculated according to the following equations:

$$WL = \frac{W_0 x_0 - W_t x_t}{W_0} \times 100 \qquad (1)$$

W_0 Mass of garlic sample at time 0 on dry basis (gr/gr)

W_t Mass of garlic sample after dehydration on dry basis (gr/gr)

x_0 Moisture fraction of garlic sample at time 0 (gr/gr)

x_t Moisture fraction of garlic sample after dehydration (gr/gr)

$$SG = \frac{W_t s_t - W_0 s_0}{W_0} \times 100 \qquad (2)$$

s_0 Solid fraction of garlic sample at time 0 (gr/gr)

s_t Solid fraction of garlic sample after dehydration (gr/gr)

$$WR = WL - SG \qquad (3)$$

-Texture analysis

Texture properties of the dried samples were measured using a TA-XT2i texture analyzer (Stable Micro Systems Ltd., Vienna Court, Lammas Road, Godalming, Surrey GU7 1YL, UK). A rod of 3.1 mm diameter was used to measure the force required to penetrate individual garlic gloves. The values of punch force reported are the mean of 5 measurements conducted at crosshead speed of 50 mm/min. The hardness is the amount of maximum force required to break the sample.

-Shrinkage

The bulk shrinkage of the garlic bulbs was measured by displacement method using toluene according to Yun Deng and Yanyun Zhao (2008). Shrinkage was calculated as the percentage change from the initial apparent volume. The % shrinkage was calculated as

$$SH = \frac{V_0 - V_f}{V_0} \times 100 \qquad (4)$$

V_0 Volume of garlic sample at time 0 (mL)

V_f Volume of garlic sample after dehydration (mL)

-Experimental design and statistical analysis

Response surface methodology (RSM) was used to investigate the effects of process variables namely osmotic solutions concentration (X_1), solution temperature (X_2), operation pressure (X_3), immersion time (X_4) and microwave power (X_5) on the water loss (WL), solid gain (SG), weight reduction (WR), hardness (HD), drying time (DT) and shrinkage (SH). A Central Composite Rotatable Design (CCRD) including 26 experiments formed by 5 central points was used (Table 1).

Results and Discussion

-Water loss and solid gain

The analysis of variance showed that the osmotic solution concentration significantly affected the water loss and solid gain at 5% level of significance.

It can be observed from Figs. 1 and 2 that both the water loss and the solid gain by garlic samples increased by increasing concentration of osmotic solution (8–20%). This was expected because the osmotic driving potentials for water as well as for solid would increase with the increased salt concentration in osmotic solution. Such effects have also been reported in other fruits and vegetables (Sagar, 2001; Sacchetti *et al.*, 2001; Corzo & Gomez, 2004; Changrue, 2006).

The temperature of osmotic solution was found to be significantly affecting on the water loss and solid gain at 5% level of significance.

Table 1. Experimental values of response variables for central composite rotatable design

Run	X_1 (%)	X_2 (°c)	X_3 (mbar)	X_4 (min)	X_5 (W)	WL (%)	SG (%)	WR (%)	HD (N)	DT (min)	SH (%)
1	12.75	45	533.66	162.50	300	8.09	3.58	4.51	5.28	35	12.31
2	17	55	692.10	240.00	180	16.98	6.33	10.65	3.14	42	13.85
3	12.75	63	533.66	162.50	300	13.25	1.42	11.83	1.44	64	15.38
4	12.75	45	241.82	162.50	300	8.18	2.75	5.43	3.36	46	12.31
5	12.75	45	533.66	21.36	300	2.162	0.26	1.902	3.21	46	15.38
6	20.49	45	533.66	162.50	300	13.71	6.95	6.76	6.19	31	13.85
7	12.75	45	825.51	162.50	300	7.73	4.42	3.31	5.34	33	12.31
8	12.75	45	533.66	162.50	100	8.1	3.8	4.3	3.89	250	15.38
9	17	55	375.23	85.00	180	8.65	5.27	3.38	2.67	44	13.85
10	17	35	375.23	85.00	450	6.54	3.6	2.94	5.00	30	13.85
11	8.5	35	375.23	240.00	450	7	4.25	2.75	9.37	31	12.31
12	8.5	55	375.23	240.00	180	6.5	0.42	6.08	4.87	63	16.92
13	8.5	55	375.23	85.00	450	5.44	2.7	2.74	2.65	21	13.85
14	17	35	692.10	240.00	450	8.86	5.2	3.66	3.40	30	13.85
15	12.75	45	533.66	162.50	600	10.27	4.8	5.47	3.48	23	15.38
16	5.01	45	533.66	162.50	300	3.45	1.67	1.78	2.70	45	12.31
17	12.75	45	533.66	162.50	300	9	4.3	4.7	5.10	33	15.38
18	12.75	45	533.66	162.50	300	10.55	5.033	5.517	5.67	44	12.31
19	17	55	692.10	85.00	450	5	1.57	3.43	6.13	26	13.85
20	8.5	35	692.10	85.00	180	4.47	3.39	1.08	6.30	56	15.38
21	8.5	55	692.10	240.00	450	7.95	2.15	5.8	2.33	21	13.85
22	12.75	45	533.66	162.50	300	8.84	4.14	4.7	5.18	35	15.38
23	12.75	45	533.66	162.50	300	9.2	4.25	4.95	5.25	40	12.31
24	12.75	26	533.66	162.50	300	5.3	2.75	2.55	2.32	52	15.38
25	17	35	375.23	240.00	180	8.4	3.4	5	4.74	60	12.31
26	12.75	45	533.66	303.64	300	9.26	3.48	5.78	6.32	41	15.38

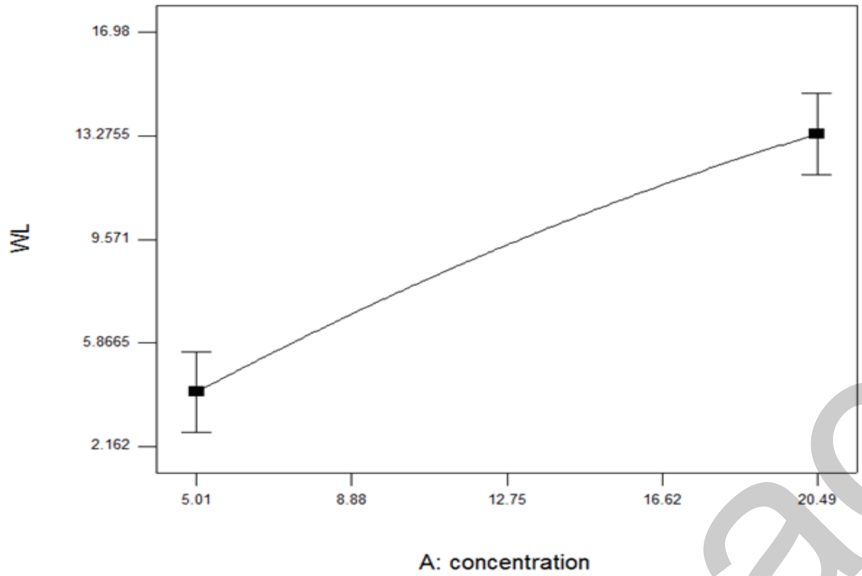

Fig. 1. The effects of NaCl concentration on WL of garlic samples

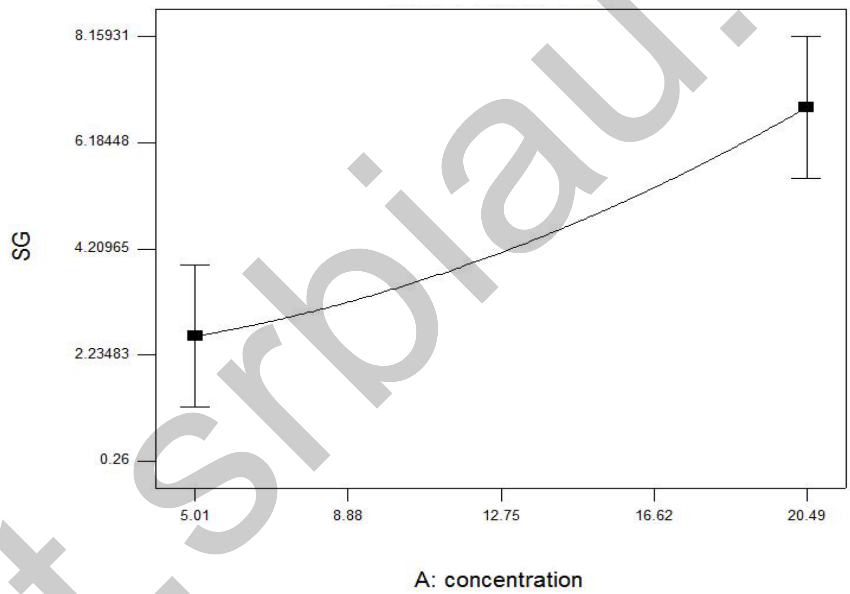

Fig. 2. The effects of NaCl concentration on SG of garlic samples

It was observed from Figure 3 that the water loss by garlic bulbs increased with increasing temperature of osmotic solution from 25°C to 65°C. Increase in mass transfer due to increase in solution temperature resulted because higher temperature seems to promote faster water loss through swelling and plasticizing of cell membranes, faster water diffusion within the product and better water transfer characteristics on the product surface due to lower viscosity of the osmotic medium. According to Fig. 4 the solid gain was increased with increasing temperature of osmotic solution from 25°C to 45°C. For higher temperatures (>45ºC), the solid gain was lower, probably due to the modification of the fruit tissue (softening), which could have resulted in a higher resistance to solution impregnation due to the shrinkage and therefore, decrease of the pore spaces. On the other hand, the modification of the cell membrane might cause it to become less selective, and this might facilitate the native liquid outflow from the cell. This increase of water loss without a great modification of solid gain when process temperature is increased has been observed by many authors (Ponting, 1966; Hawkes & Flink, 1978; Islam & Flink, 1982; Corzo, 2007).

The analysis of variance for effect of immersion time (20-300 min) on mass transfer showed highly significant difference in water loss and solid gain (Figures 5 and 6).

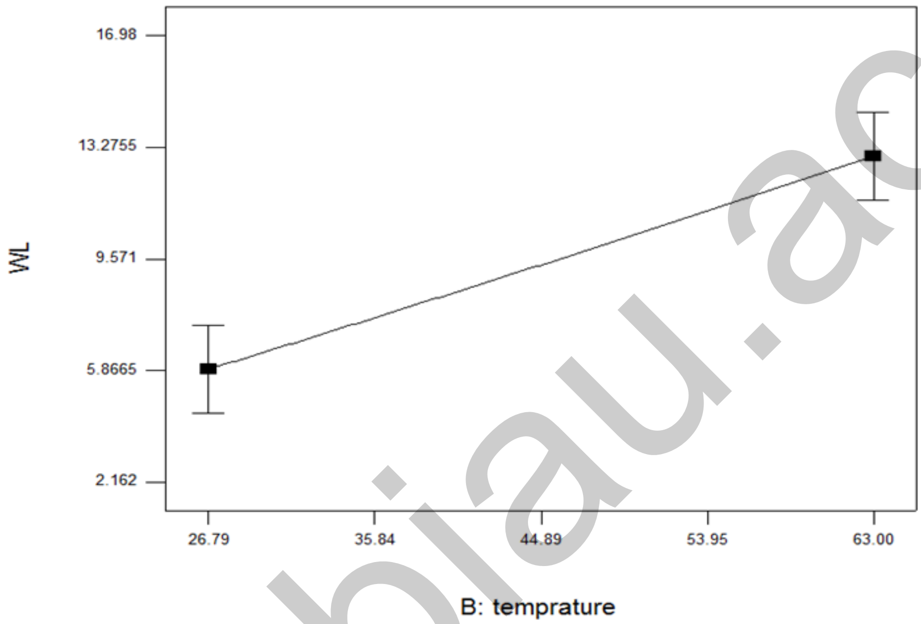

Fig. 3. The effects of temperature on WL of garlic samples

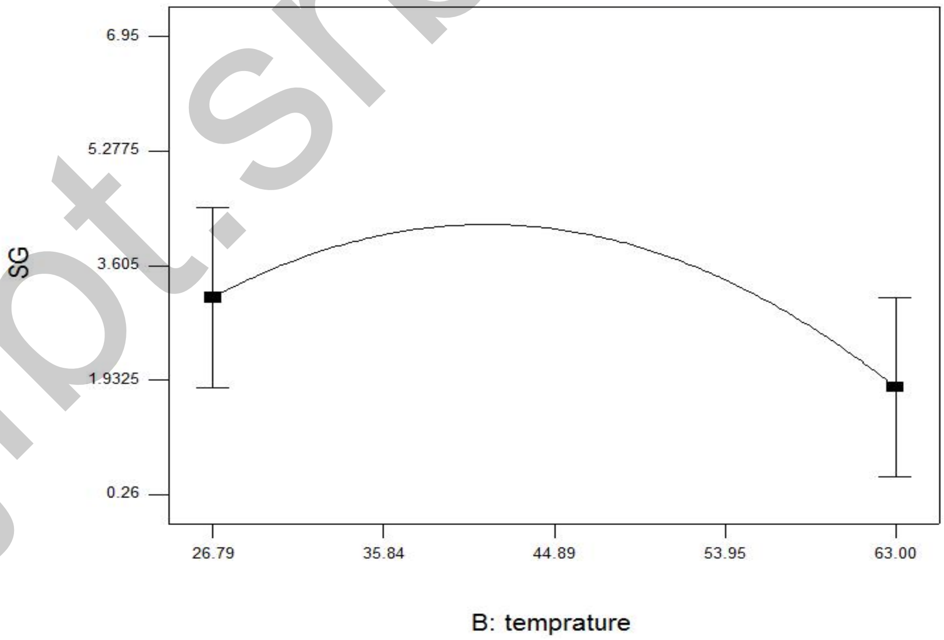

Fig. 4. The effects of temperature on SG of garlic samples

The water loss as well as solid gain increased non-linearly with immersion time. Both, the water loss and solid gain were faster in the initial period of osmotic dehydration and then the rate decreased. This was expected because osmotic driving potentials for moisture as well as solid transfer will keep on decreasing with time as the moisture keeps moving from sample to the solution and the solid from solution to the sample. Further, progressive solid uptake would result in the formation of high solid subsurface layer, which would interfere with the concentration gradients across the sample-solution interface and would act as a barrier against the removal of water and uptake of solid. Besides, rapid loss of water and uptake of solid near the surface in the beginning may result in structural changes leading to compaction of these surface layers and increased mass transfer resistance for water and solid (Lenart, 1996). Similar trends have been reported for other fruits and vegetables during osmosis (Sacchetti *et al*., 2001; Corzo & Gomez, 2004; Changrue, 2006).

The analysis of variance shows significant interaction correlation between NaCl concentration and immersion time, and between temperature and immersion time and are shown in Figures 7 and 8, respectively.

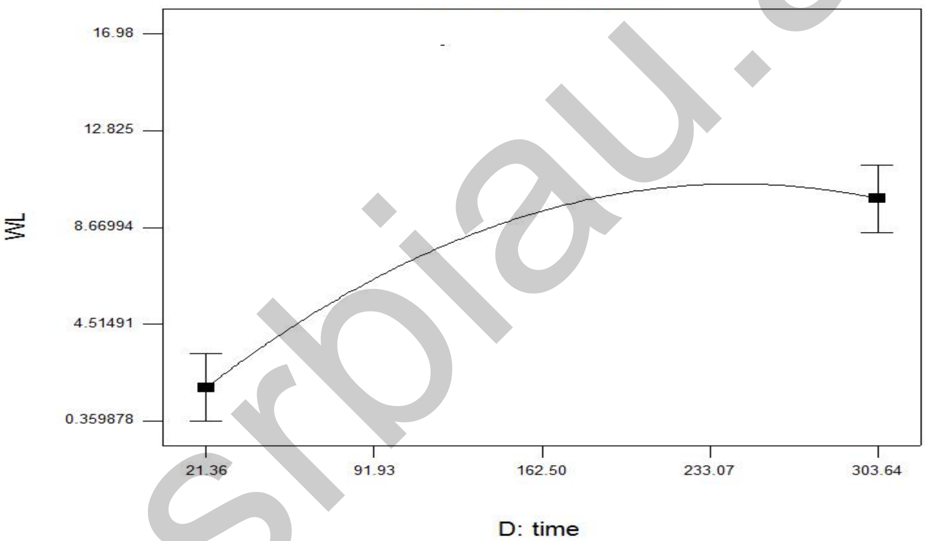

Fig. 5. The effects of immersion time on WL of garlic samples

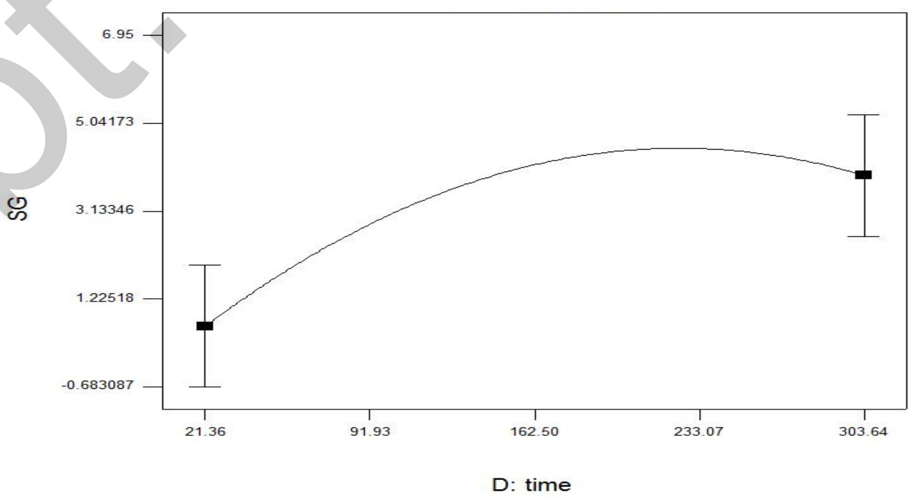

Fig. 6. The effects of immersion time on SG of garlic samples

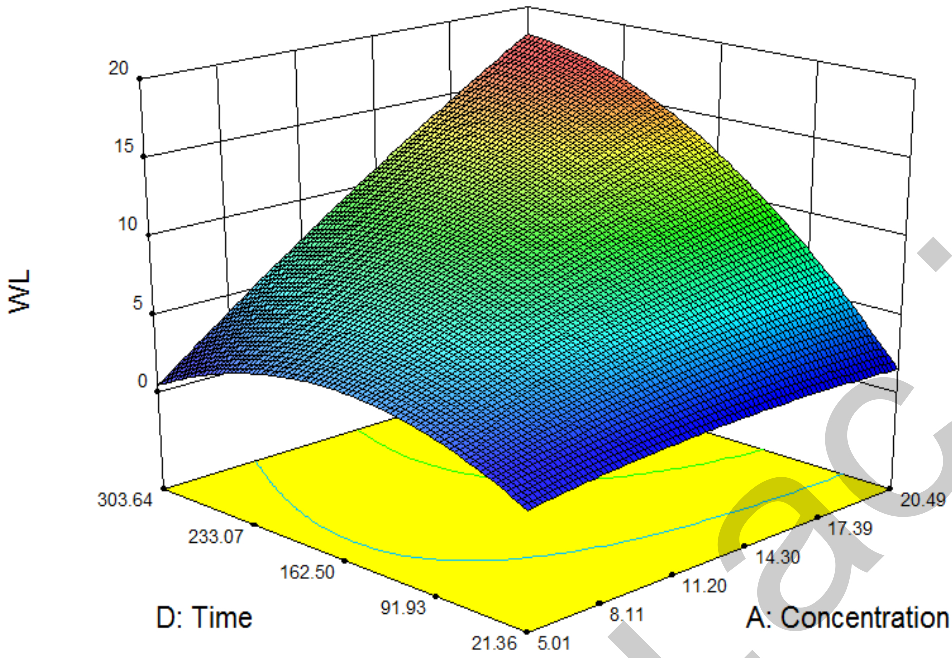

Fig. 7. The interaction effect of concentration and time on WL of garlic samples

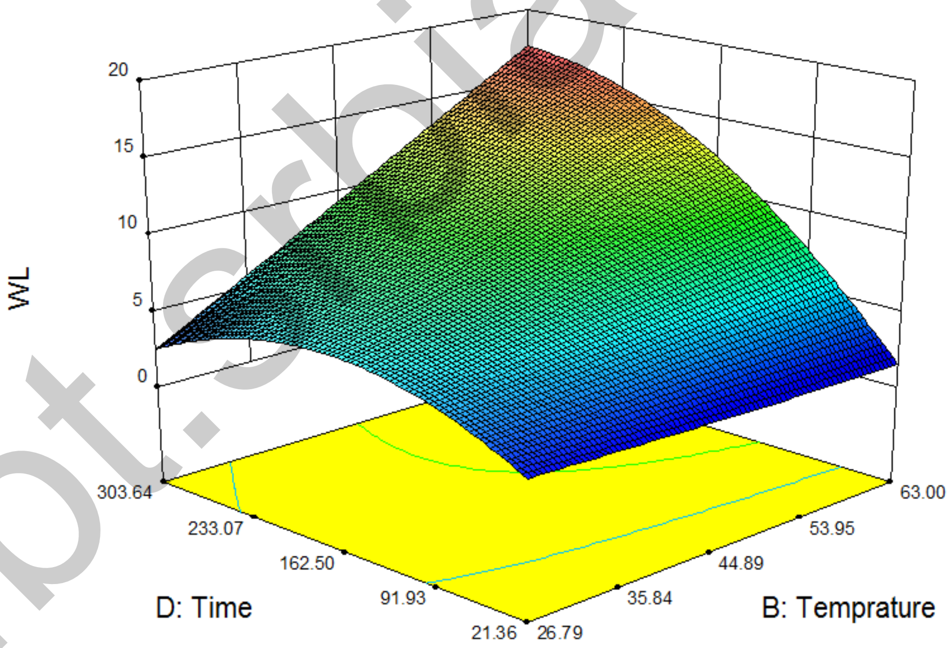

Fig. 8. The interaction effect of temperature and time on WL of garlic samples

-*Weight reduction (WR)*

WR is dependent on the other variable (SG, WL), and the difference of WL and SG results in WR. According to the results presented in Fig. 9, 10 and 11, WR in garlic were affected by the NaCl concentration, immersion time and temperature. WR increased with increasing osmotic solution concentration, temperature and immersion time. It was observed from Fig. 9 and 10 that the weight reduction by garlic increased with increasing concentration of osmotic solution from 5% to 15% and with increasing immersion time from 20 to 240 min. According to fig. 11 the weight reduction was increased with increasing temperature of osmotic solution from 25°C to 65°C.

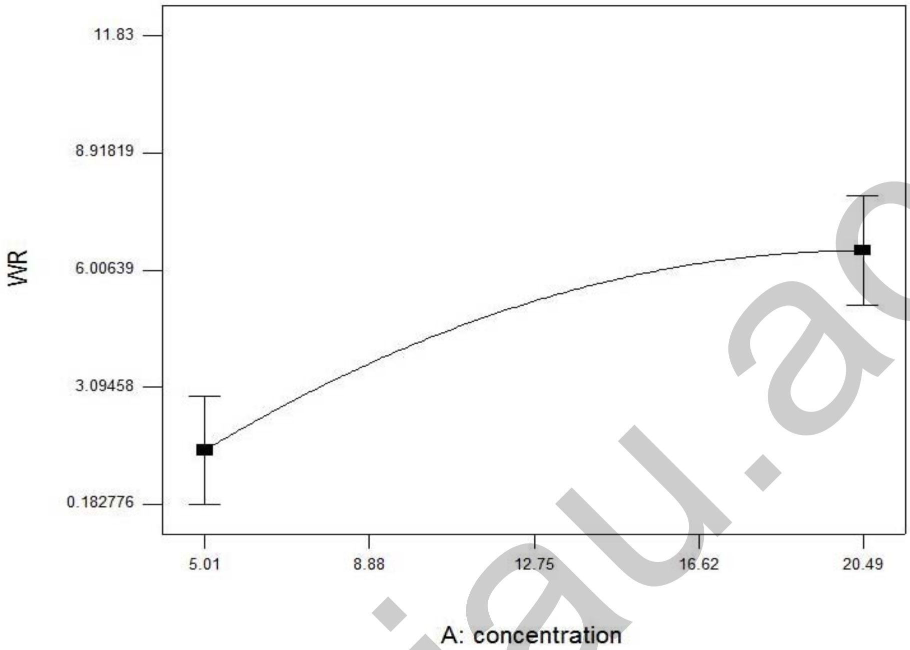

Fig. 9. The effects of concentration on WR of garlic samples

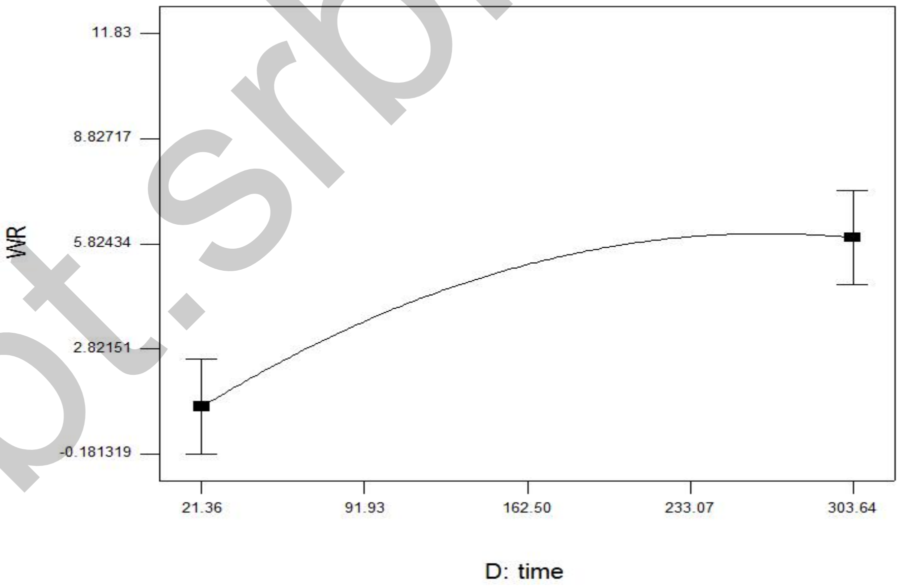

Fig. 10. The effects of immersion time on WR of garlic samples

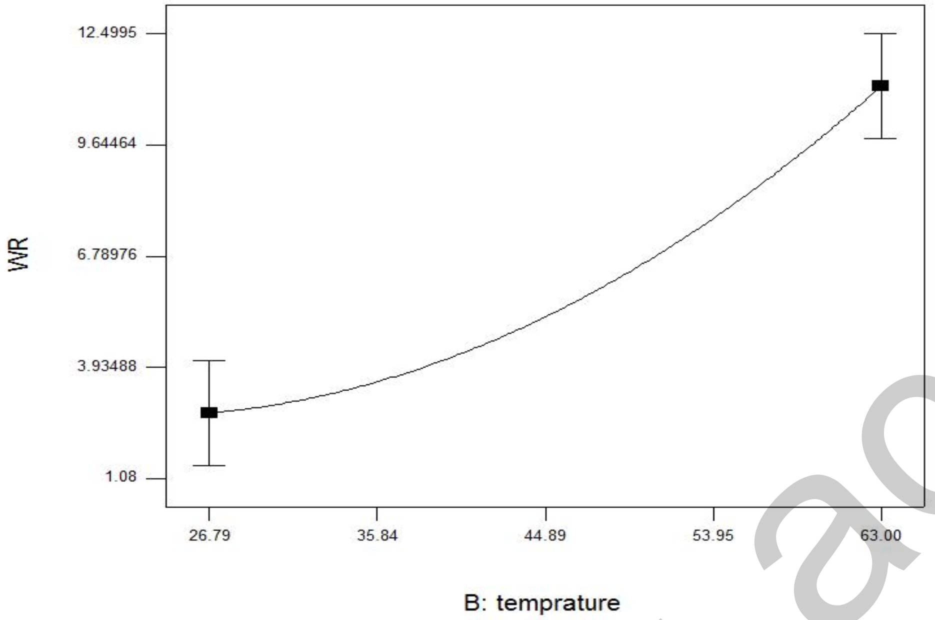

Fig. 11. The effects of temperature on WR of garlic samples

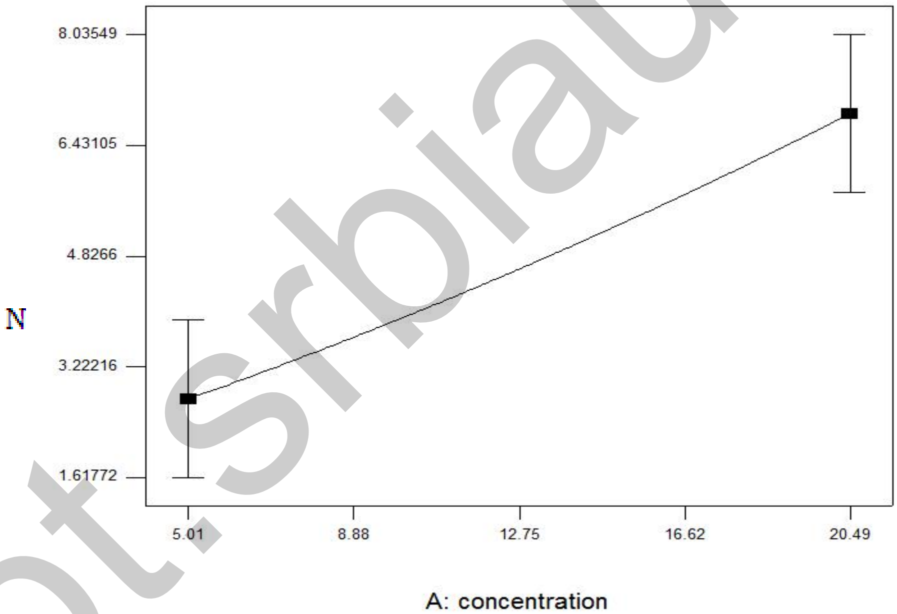

Fig. 12. The effects of concentration on hardness of garlic samples

-Texture and shrinkage

Based on the results of percentage of volume change on garlic cloves, it was noticed that lowering of moisture content to 6% did not cause considerable change in shrinkage (P< 0.05).

Texture properties of dried samples are dependent on the behaviour of cellular matrix and soluble solid phase inside the tissue; both with different interactions with water (Contreras *et al*., 2005). Table 2 shows that osmotic solution concentration, temperature and immersion time had a significant effect (P<0.05) on the compressive strength. Hardness increased with increasing osmotic solution concentration and immersion time due to increasing solid gain and decreasing pores and cavities of garlic. This agreed with the report from Yun Deng and Yanyun Zhao (2008). Hardness increased with increasing osmotic solution temperature from 25°C to 45°C due to increasing NaCl diffusion in intercellular spaces and obtaining a more compact structure. For higher temperatures hardness decreased due to breakdown of cell walls, a decreased intercellular contact and collapse of cell structure of samples.

According to Figure 2 the result shows significant interaction correlation between NaCl concentration and immersion time, and between temperature and operation pressure. Their effects were similar effect between NaCl concentration and immersion time; and between temperature and pressure on SG.

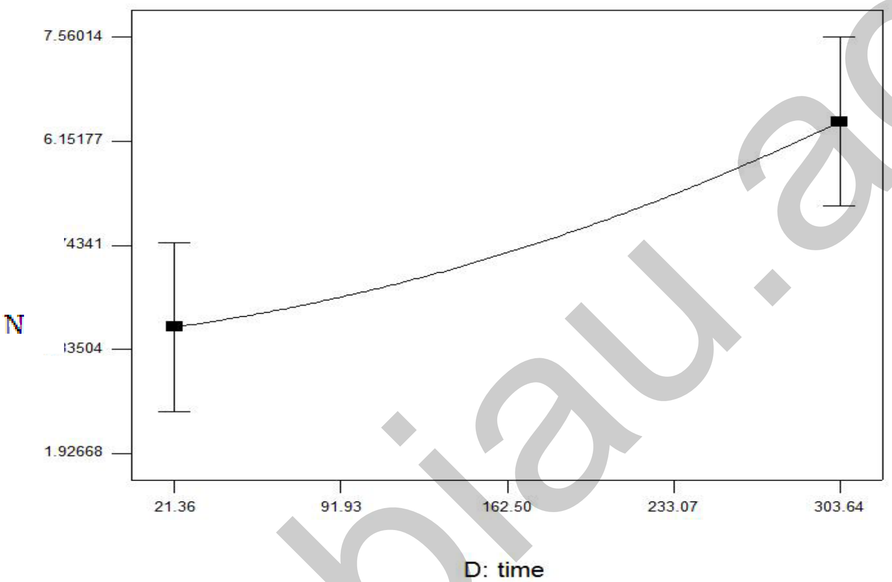

Fig. 13. The effects of immersion time on hardness of garlic samples

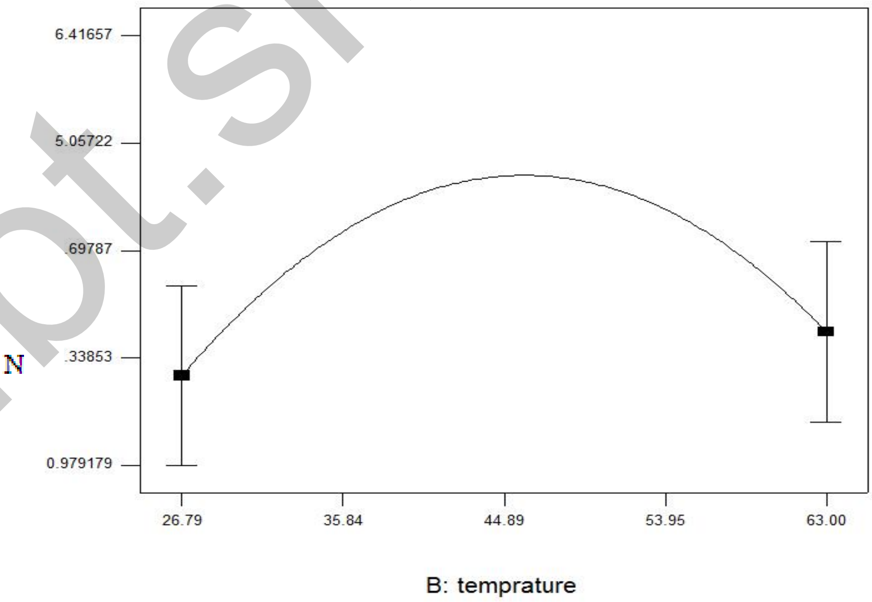

Fig. 14. The effects of temperature on hardness of garlic samples

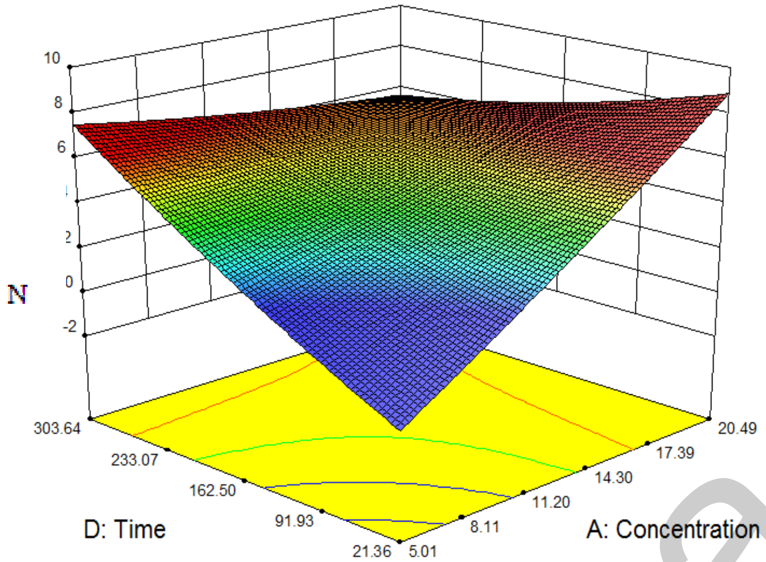

Fig. 15. The interaction effect of concentration and time on hardness of garlic samples

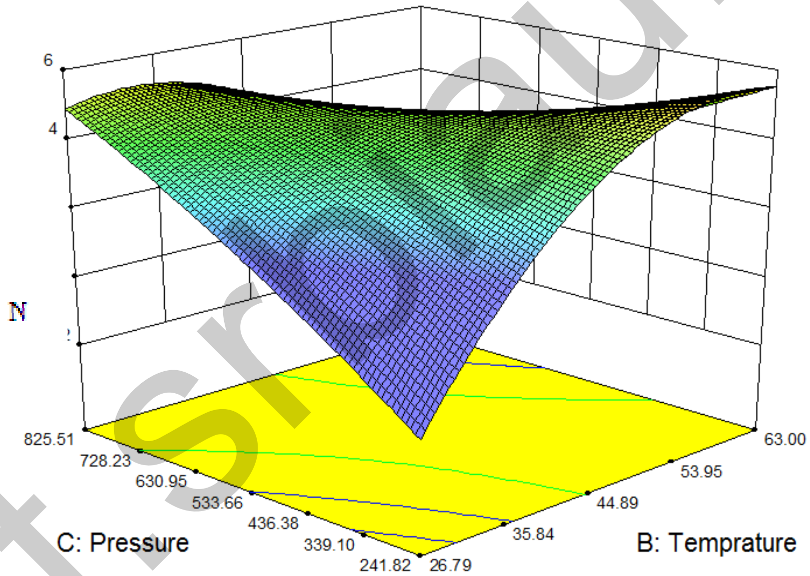

Fig. 16. The interaction effect of pressure and temperature on hardness of garlic samples

Drying time

The results show that microwave power had a significant effect ($P<0.05$) on the drying time. Figure 17 showed that as microwave power increased, drying time decreased. It can be seen that as power increased, internal vapour pressure increased which could be explained by more internal heat generated at higher powers. The higher pressure led to more rapid moisture removal. This observation is in agreement with previous literature studies on microwave drying of food products (Souraki *et al.*, 2009; Al-Harahsheh *et al.*, 2009; Wang & Sheng, 2006).The analysis of variance shows significant interaction correlation between NaCl concentration and microwave power and between osmotic immersion time and microwave power.

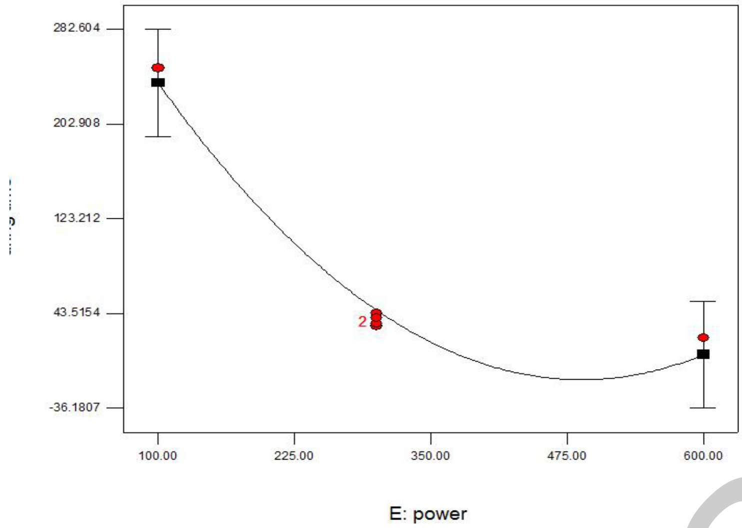

Fig. 17. The effects of microwave power on drying time of garlic samples

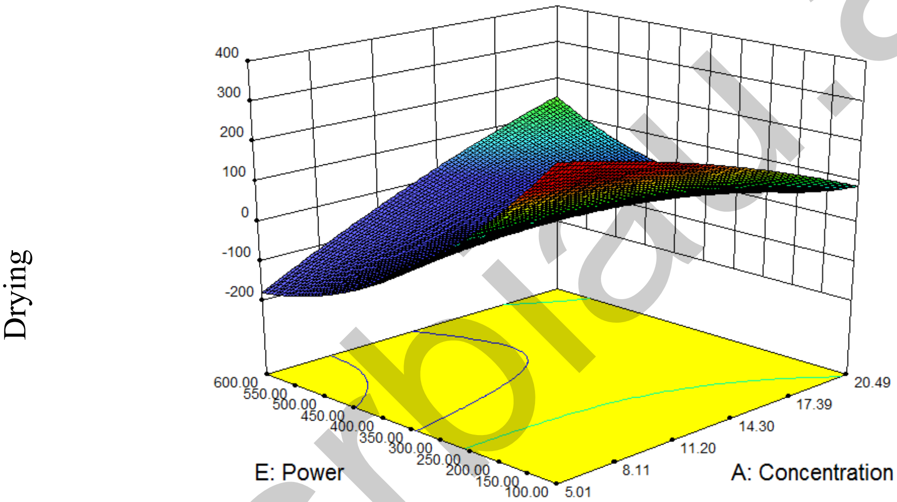

Fig. 18. The interaction effect of microwave power and osmotic concentration on drying time

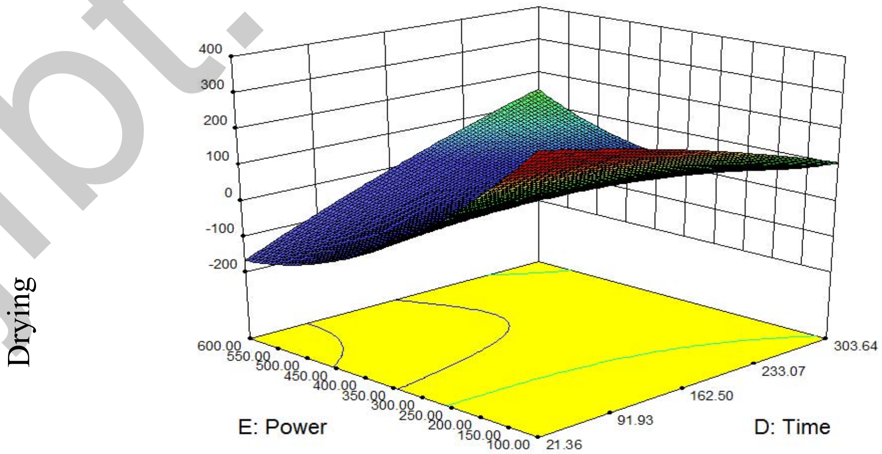

Fig. 19. The interaction effect of microwave power and osmotic immersion time on drying time

-Predictive equations

Data was analysed using the software package Design-Expert. The model was developed from regression coefficients under a range of experimental factors. The terms of second order polynomial model consist of linear, quadratic (squared) and interaction terms as shown by the following equation:

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_{11}X_1^2 + b_{22}X_2^2 + b_{33}X_3^2 + b_{44}X_4^2 + b_{55}X_5^2 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{14}X_1X_4 + b_{15}X_1X_5 + b_{23}X_2X_3 + b_{24}X_2X_4 + b_{25}X_2X_5 + b_{34}X_3X_4 + b_{35}X_3X_5 + b_{45}X_4X_5 \quad (5)$$

Where b_n are the regression coefficients; Y is the response of WL, SG, WR, δ_{MAX}, Shrinkage and drying time of garlic; X1, X2, X3, X4 and X5 in Eqn. (6) are NaCl concentrations (% w/w), temperature (°C), pressure (mbar), immersion time (min) and microwave power (w).

Regression coefficients of Equation (6) for the predictive models WL, SG and WR of garlic as shown in Table 2 provided the predictive equations in actual terms as the following:

$$WL\ (\%) = -31.94 + 0.699(co) + 0.091(T) + 0.057(Pr) - 0.030(t) + 0.0676(P) - 0.011(co)^2 + 0.0002(T)^2 - 0.00001\ (Pr)^2 - 0.0002(t)^2 - 0.000004(P)^2 + 0.0069(co)\ (T) - 0.0006(co)\ (Pr + 0.0039(co)\ (t) - 0.0013(co)\ (P) - 0.0002(T)\ (Pr) + 0.0015(T)\ (t) - 0.0005(T)\ (P) - 0.00005(Pr)\ (t) - 0.00006(Pr)\ (P) + 0.00007(t)\ (P) \quad (6)$$

$$SG\ (\%) = -37.30 + 0.285(co) + 0.619(T) + 0.050(Pr) + 0.042(t) + 0.038(P) + 0.0095(co)^2 - 0.0050\ (T)^2 - 0.000002(Pr)^2 - 0.00009(T)^2 + 0.000007\ (P)^2 + 0.013(co)\ (T) - 0.0004(co)\ (Pr) - 0.0009(co)\ (t) - 0.0013(co)\ (P) - 0.0007(T)\ (Pr) - 0.00007(T)\ (t) + 0.000007(T)\ (P) + 0.00002(Pr)\ (t) - 0.00005(Pr)\ (P) + 0.000005(t)\ (P) \quad (7)$$

$$WR\ (\%) = 5.363 + 0.414(co) - 0.528(T) + 0.007(Pr) - 0.073(t) + 0.030(P) - 0.020(co)^2 + 0.005(T)^2 - 0.000013(Pr)^2 - 0.000083(t)^2 - 0.000012(P)^2 - 0.006(co)\ (T) - 0.00017(co)\ (Pr) + 0.005(co)\ (t) - 0.000034(co)\ (P) + 0.0005(T)\ (Pr) + 0.0016(T)\ (t) - 0.0005(T)\ (P) - 0.000078(Pr)\ (t) - 0.000016(Pr)\ (P) + 0.000071(t)\ (P) \quad (8)$$

$$\delta_{MAX} = -47.686 + 0.759(co) + 0.810(T) + 0.067(Pr) + 0.091(t) + 0.0075(P) + 0.0031(co)^2 - 0.0069(T)^2 - 0.000004(Pr)^2 + 0.00002(t)^2 - 0.00001(P)^2 - 0.0024(co)\ (T) - 0.0004(co)\ (Pr) - 0.0027(co)\ (t) + 0.0005(co)\ (P) - 0.0006(T)\ (Pr) - 0.00005(T)\ (t) + 0.0005(T)\ (P) - 0.00008(Pr)\ (t) - 0.00005(Pr)\ (P) - 0.00002(t)\ (P) \quad (9)$$

$$Shrinkage = 14.02 \quad (10)$$

$$drying\ time = 866.53 + 11.98\ (co) - 1.36\ (T) - 1.23\ (Pr) + 0.87\ (t) - 3.39\ (P) - 0.37(co)^2 - 0.008(T)^2 - 0.0002(Pr)^2 - 0.0008(co)^2 + 0.002(P)^2 + 0.04\ (co)\ (T) - 0.08\ (co)\ (Pr) + 0.07\ (co)\ (t) + 0.02\ (co)\ (P) - 0.04\ (T)\ (Pr) + 0.024\ (T)\ (t) + 0.002\ (T)\ (P) - 0.002\ (Pr)\ (t) + 0.004\ (Pr)\ (P) - 0.008\ (t)\ (P) \quad (11)$$

Where, Co = concentration (%w/w), $5 < Co < 21$,

T = Temperature (°C), $25 < T < 63$,

Pr = pressure (mbar), $241 < Pr < 826$

t = Time (min), $20 < t < 304$ and p = Power (w), $100 < P < 600$.

Conclusion

Analysis of the results indicated that increases in the osmotic solution concentration, temperature and immersion time, caused increases in WL and WR noticeably. The effect on SG was almost the same except for temperatures higher than 45°C in which increasing temperature resulted in a decrease in SG. Vacuum pressure from 240 to 830 mbar did not cause considerable changes in WL, SG and WR.

Garlic texture is affected predominantly by osmotic solution concentration, temperature and immersion time. Therefore as a result of increasing concentration and immersion time, dried garlic becomes harder. Increasing temperature from 20°C to 45°C also makes the texture harder. For temperatures higher than 45°C, garlic texture becomes softer. Microwave power had a significant effect on the drying time and as the power increased, drying time decreased.

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