

Modelling the Hydration kinetics of kidney beans (*Phaseolus vulgaris*) in sodium salts using Response surface methodology

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Abstract

The present work investigated the effect of salt solutions of sodium chloride, and sodium bicarbonate on the water uptake by kidney beans (*Phaseolus vulgaris*) at different temperatures (30, 45 and 60 °C). Thirty-five soaking solutions were prepared using NaCl and NaHCO₃ to find the optimum soaking treatment and time to maximise the hydration. Hydration kinetics of kidney beans was studied in different concentrations of the salt solutions and at different temperatures by the method of weight gain until equilibrium conditions were attained. Response surface methodology was used to design the experiments and to optimize the levels for minimum soaking time and to maximize the hydration. The soaking solutions affected the mass transfer in both seed coat and cotyledon, demonstrating changes on both proteins and polysaccharides. Increasing the temperature from 30 to 60 °C in sodium chloride solution and sodium bicarbonate solution (0.5, 1.0 and 1.5% concentration) decreased the soaking time from >225min and 225 min to 82.5 min and 73.5 min respectively to achieve around 80% hydration. Beans soaked in sodium bicarbonate solution exhibited higher hydration rates than in distilled water followed by sodium chloride solution at the same salt concentration. Soaking for about three hours at 30°C resulted in maximum hydration. The optimum soaking treatment was found to be in a salt solution containing 1.10% NaCl and 0.92% NaHCO₃ at 30°C which resulted in a soaking time of 193.45 min. This work demonstrated a simple and non-tedious approach for enhancing the hydration process of grains.

Keywords: Hydration, Kidney bean, Response surface methodology, Salt solution

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INTRODUCTION

The consumption of kidney beans (*Phaseolus vulgaris* L.) is primarily for their pods and seeds (Choung *et al.*, 2003), and are widely used in Asian countries in traditional foods. They are used in various processed foods such as bakery products, salads, and canned food and are considered to be versatile dietary ingredients (Nciri *et al.*, 2015). Cereals and legume processing often involve hydration of seeds first to facilitate cooking or canning operations. Thus, water adsorption into seeds is of both theoretical and practical interest to grain processing industries (Hsu, 1983; Taiwo *et al.*, 1998; Schoeninger *et al.* 2017; Miano and Augusto, 2018).

Dry Beans (*Phaseolus vulgaris* L.) require a long cooking time to achieve the desired digestibility

(Uebersax *et al.*, 1991). Therefore, hydration of beans before cooking is necessary to decrease the cooking time and increase the drained weight (Taiwo *et al.*, 1998; Mustafa *et al.*, 2015). Besides reducing the cooking time, it also results in a softer drained texture and partial removal of oligosaccharides, stachyose and raffinose responsible for flatulence (Nelson and Hsu, 1985; Abd El-Hady and Habiba 2003). There are also some reports on the optimization of the soaking condition of black gram dal in order to reduce the flatugenic sugar content (Rakshit *et al.*, 2015). Soaking is a time-consuming process that involves the diffusion of water into the grain (Engels *et al.*, 1986). Thus, soaking at room temperature may provoke microbial spoilage (Miano and Augusto, 2018), which affects the quality attributes (such as color, taste, and smell) of the product (Bello *et al.*, 2004). So

several attempts have been made to shorten it. Many (Kon,1979; Piergiovanni, 2011; Oliveira et al., 2013; Miano et al. 2015) employed soaking at elevated temperature for reducing the soaking time. However, it resulted in significant losses of total solids, nitrogenous compounds, total sugars, calcium, magnesium, and water-soluble vitamins.

Vacuum filtration techniques have also been employed to accelerate the soaking of lima beans (Rockland and Metzler, 1967) and soyabean (Xiao et al., 2015). Numerous studies have reported the beneficial effects of soaking in salt solutions before cooking or using various salt solutions in the cooking of pulses. Few studies, however, concluded that the sodium salts in water did not significantly affect the amount of water absorbed by beans, but the pH of the solution is a critical determinant (Varriano- Marston and De Omana, 1979 and Avila et al., 2015).

From the processing and engineering standpoint, it is required not only to know the time required to attain equilibrium moisture content but also the effect of processing variables and the prediction of soaking time under given conditions. Various models have been used to predict the quantitative analysis of water absorption for cereal grains, but the suitability for applying these models to describe the absorption in legumes remains to be determined. A good model can replace experiments that may be difficult to perform and can aid in the process scale-up (Clark, 1978). Therefore, the aim of the present investigation was (1) to study the effect of various soak solutions of sodium salt, their concentration and the temperature on hydration kinetics of beans (2) to find out a suitable model which fits the hydration kinetics of beans and (3) to optimize (minimize) the soaking time of beans in mixed salt solution.

MATERIALS AND METHODS

Dry kidney beans (*Phaseolus vulgaris* L.) of *Chitra* cultivar were procured from the local market in Pantnagar, India. Beans were sorted manually for removing small, split, and defected beans. Beans were stored at room temperature (23- 24°C) in airtight plastic containers to prevent moisture changes during storage.

Experimental Plan: Response Surface Methodology involving designing of experiments, selection of levels of variables, fitting mathematical model, and finally selecting variable levels by optimizing the response (Khuri and Cornell, 1987) was employed in the present study. The general factorial and box Behnken design was used to design the experiments. In general factorial, two independent variables - salt concentration and temperature at three levels were used. In box Behnken design (Tables 1 and 2), three independent variables at three levels were used. Independent variables included salt concentrations of sodium chloride

(0.5, 1.0 and 1.5%), salt concentrations of sodium bicarbonate (0.5, 1.0 and 1.5%) and temperature (30, 45 and 60°C).

Determination of moisture content: Dry beans were ground in a domestic grinder, and the resultant bean flour was sieved through a 1 mm screen. Ten gram of the flour in triplicates was dried to a constant weight in an oven at 100°C, and the moisture content was determined using AOAC (1984) method.

Determination of water absorption during soaking: Ten gram of dry beans were soaked in 50 ml soak solutions using a thermostatically controlled water bath at three soaking temperatures: 30, 45, and 60° C. Water absorption was recorded every 15 min. initially due to rapid water uptake and then at 30 min. and one hour due to a decline in the water absorption rate as equilibrium conditions were reached. After the specified time interval, beans were removed from soaking solutions, spread over the tissue paper to remove superficial water, and weighed. The weight gain was recorded (Wood and Harden, 2006) and the beans were put back into the soaking solution, maintained at the required temperature. Water absorption was recorded until there was insignificant difference between two consecutive weights. Experiments were conducted in triplicates, and the results reported as g H₂O/ 100g dry beans (% dwb).

Mathematical Modelling: Mathematical equations were developed to relate the amount of water absorbed during hydration to the hydration time for different soaking temperatures, salts, and salt concentration considered in the study. Various models were analyzed using the CURVEFIT software and the best fit model for the data was fitted into the primary response (hydration rate, y). The adequacy of the model was tested using the coefficient of determination (R²). The constants (a, b) of the model were, thereafter, determined using NLREG software. These values were further used to evaluate the secondary response x (hydration time) for 80 percent hydration (y) using the model. The regression equation was then evaluated for 80 percent hydration rate. A complete second-order model was fitted into the response (hydration time) for mixed solutions. The adequacy of the model was tested using a coefficient of determination (R²), Fisher’s F-test and lack of fit test. The model was then used to interpret the effects of variables. Contour plots were drawn for showing the effect of independent variables on the response and to select the range of variables for optimum process. The hydration conditions were then optimized using Design Expert 8.0.3.1 where the hydration time and temperature were minimized. A second order response function for three independent variables has the following form:

$$Y = \beta_0 + \sum_{i=1}^K \beta_1 X_i + \sum_{i=1}^K \beta_2 X_i^2 + \sum_{i=1}^{K-1} \sum_{j=i+1}^K \beta_{ij} X_i X_j, \dots \dots \dots$$

Eq.1

Where,
 $\beta_0, \beta_{ii}, \beta_{ij}$ are constants
 X_i, X_j are variables (coded)

RESULTS AND DISCUSSION

The hydration by beans at different temperatures, in individual and combined salt solution are shown in Tables 3, 4 and 5.

Effect of soaking time: The water absorption curves (Fig 1 and 2) initially showed a high hydration rate followed by a decline in later stages, which is characteristic of moisture sorption behaviour. This is attributed to the gradual filling of capillaries at the surface of seed coats and at the hilum of black beans and Andean lupins (Hsu et al., 1983; Miano et al., 2015) in the initial phases which increased the water uptake. This is followed by a decline in water absorption due to cumulative effects of increased solute extraction, filling of free capillaries and intermicellar spaces with water (Phlak et al., 1989; Sayar et al., 2001; Miano and Augusto, 2015). Also with prolonged soaking time, the amount of water absorbed stabilized (Taiwo et al., 1998; Wood and Harden, 2006) in legumes due to resisted swelling by the unsolvated structural network of solids which leads to the development of internal pressure and thereby less swelling for the same degree of moisture absorbed (Singh and Kulshreshtha, 1987; Wood and Harden, 2006).

Table 1. Experimental variables for soaking treatments, their coded and uncoded (actual) values.

Variables	Code	Coded level		
		-1	0	+1
NaCl concentration (%)	X ₁	0.5	1.0	1.5
NaHCO ₃ concentration (%)	X ₂	0.5	1.0	1.5
Temperature (°C)	X ₃	30	45	60

Table 2. Experimental design matrix (Box Behnken design) for soaking treatment and levels in coded and uncoded form.

Experiment No.	Coded (real values)		
	X ₁	X ₂	X ₃
	(NaCl concentration)	(NaHCO ₃ concentration)	(Temperature)
1	-1	-1	0
2	+1	-1	0
3	-1	+1	0
4	+1	+1	0
5	-1	0	-1
6	+1	0	-1
7	-1	0	+1
8	+1	0	+1
9	0	-1	-1
10	0	+1	-1
11	0	-1	+1
12	0	+1	+1
13	0	0	0
14	0	0	0
15	0	0	0
16	0	0	0
17	0	0	0

Effect of temperature: Beans soaked at 60°C approached equilibrium faster than at 30°C. Also, there was a decrease in the maximum water uptake of beans (Fig.1). Similar results were reported previously (Taiwo et al., 1998). These effects are possibly modulated due to increased mass transfer resulted due to altered cell membrane permeability as well as increased gas pressure in the interior of kidney beans (Abu-Ghannam, 1998).

Effect of salt: Soaking in NaHCO₃ solution over a temperature range of 30-60°C resulted in a more rapid and greater water uptake than beans hydrated in NaCl at the same salt concentration (Fig 2). This could be due to the degradation of pectic substances, decreased proportion of calcium pectate resulting from the chelation of calcium, and increased charge density of proteins resulting from ionization of amino acid side chains at high pH. This results in increased content of soluble nitrogen, as reported in black beans (Varriano-Marston and De Omana, 1979). Increased water uptake by soaking in NaHCO₃ solution was reported previously also in faba beans and yam beans (Haladjian et al., 2003; Aminigo and Metzger, 2005; Avila et al., 2015).

Effect of salt concentration: It was found that soaking in increased concentrations of NaCl and NaHCO₃ at higher temperatures decreased the hydration rate significantly (Fig. 1c and 1f) (Kader, 1995) contrary to the one reported by Avila et al., 2015 in cowpeas. This may be due to increased osmotic gradient across the cotyledon membranes resulting due to the mutual effect of increased salt concentration in the soaking water and more leached solids at a higher temperature (Onyeike and Uzogara, 2000)

Optimizing the soaking time in mixed salt solution: The model, $y = ax^b$ (power-law) was

found to be the best fit for the data where y is the water absorbed and x is the hydration time. The constants a and b at different conditions with the corresponding correlation coefficients are shown in Table 6. In a mixed salt solution of sodium chloride and sodium bicarbonate, minimum soaking time for 80 percent hydration was observed with Expt. 7 (Table 5) which corresponds to 0.5 per cent NaCl ($X_1 = -1$), 1.0 per cent NaHCO_3 ($X_2 = 0$) at 60°C ($X_3 = +1$) and soaking time of 62.64 min. The maximum soaking time (221.98 min) was seen for Expt. 10 which corresponds to 1.0 per cent sodium chloride ($X_1 = 0$), 1.5 per cent sodium carbonate ($X_2 = +1$) at 30°C ($X_3 = -1$).

The results of the regression analysis are presented in Table 7. The coefficient of determination (R^2) for the regression model of hydration time in sodium chloride and sodium bicarbonate was 93.10, which implied that the model could account for 93.10 percent data. Lack of fit was insignificant, which implied that the data could be well explained and interpreted by the model. It was seen (Table 8) that the effect of sodium chloride and sodium bicarbonate was insignificant, but the temperature had a significant effect on hydration time ($p < 0.01$) as having been reported earlier (Kader, 1995). The negative coefficient of X_3 indicated that the hydration time decreased with the increase in temperature, whereas the positive coefficient of X_1 and X_3 indicated that hydration time increased with an increase in levels of sodium chloride and sodium bicarbonate. The predictive equation is given below:

$$Y = 124.39 + 5.40X_1 + 1.47X_2 - 65.57X_3 + 2.91X_1X_2 + 8.74X_1X_3 - 2.63X_2X_3 + 10.17X_1^2 + 14.78X_2^2 + 4.12X_3^2$$

Where,

X_1, X_2, X_3 are the coded variables for sodium chloride (percent) level, sodium bicarbonate (percent) level and temperature ($^\circ\text{C}$).

ANOVA showing the effect of independent variables at a linear, quadratic and interactive level and the individual effect of variables are shown in Table 9 and 10. It shows that the effect was significant at a linear level only ($p < 0.01$) and the effect of temperature was most followed by sodium chloride and sodium bicarbonate. The contour plots are shown in Fig.3. These curves are plotted to understand the interaction of the variables and to determine the optimum level of each variable for maximum response. The higher sodium chloride concentration and sodium bicarbonate concentration in a salt solution, increased the hydration time (Fig. 3a). An increase in the temperature leads to a decrease in hydration time, while for both sodium chloride concentration (Fig. 3b) and sodium bicarbonate concentration (Fig 3c), the hydration time decreases initially and then increases with increase in concentration. The optimized levels of the variables are given in Table 11. Beans soaked

Table 3. Hydration of beans soaked in NaCl solution of different concentrations at different period.

Temp.	Hydration (%) [*]										
	Soaking time (min.)										
	7.5	22.5	37.5	52.5	67.5	82.5	97.5	120	150	180	225
0.5% salt											
30°C	2.6±1.0	5.0±1.8	8.3±2.2	12.0±2.1	16.6±2.0	21.5±2.2	27.4±1.9	39.4±2.9	52.2±3.1	62.3±3.5	75.1±3.1
45°C	3.1±0.5	9.2±0.6	14.0±3.2	26.7±0.9	38.7±2.0	50.2±4.1	60.3±6.4	70.2±4.8	76.8±3.4	81.9±2.8	88.0±1.9
60°C	21.3±4.3	39.3±8.2	52.7±8.9	64.9±10.8	72.8±10.6	79.6±10.4	84.3±10	89.4±8.6			
1.0% salt											
30°C	2.7±0.4	5.4±0.6	8.4±0.3	12.0±0.6	16.0±1.2	19.5±3.0	25.1±3.4	39.8±5.4	52.2±7.5	62.0±7.9	70.2±11.2
45°C	3.9±0.7	10.5±1.2	17.4±1.0	28.7±0.6	37.1±4.8	47.4±5.1	57.9±3.9	67.5±4.9	73.6±5.0	77.7±5.0	82.7±5.5
60°C	19.7±7.1	37.8±9.1	49.4±6.2	59.2±5.5	67.4±4.4	74.7±3.0	80.3±2.7	88.1±3.2			
1.5% salt											
30°C	2.6±0.8	5.1±1.3	8.4±1.4	12.3±1.1	16.6±1.5	21.7±1.5	27.4±2.0	40.7±5.4	53.8±7.6	63.1±7.5	76.2±9.0
45°C	4.1±0.4	10.1±1.7	18.2±3.3	26.8±4.5	35.7±4.7	45.0±6.2	53.0±9.0	64.2±9.4	71.0±8.3	75.8±7.2	82.0±5.4
60°C	15.7±1.4	31.5±1.8	42.1±1.2	53.7±1.6	62.4±1.8	70.5±2.2	76.9±2.4	84.6±2.1			

^{*}average of three determinations

Table 4. Hydration of beans soaked in NaHCO₃ solution of different concentration at different periods.

Temp.	Hydration (%)*										
	Soaking time (min.)										
	7.5	22.5	37.5	52.5	67.5	82.5	97.5	120	150	180	225
0.5% salt											
30°C	2.9±0.7	6.7±1.7	11.3±2.6	17.0±4.2	23.3±6.2	30.2±8.1	38.5±9.7	52.4±10.6	64.7±8.4	74.2±6.3	84.3±4.5
45°C	3.6±1.7	9.9±3.5	20.2±5.6	34.1±6.4	49.0±6.6	61.1±6.8	68.6±5.7	77.7±5.2	83.2±5.3	87.5±5.4	92.5±4.6
60°C	18.9±2.0	47.1±1.9	63.9±4.0	76.6±3.8	83.3±3.3	87.6±3.5	90.4±3.9	93.2±4.5	-	-	-
1.0% salt											
30°C	2.4±0.6	5.3±0.8	8.6±1.3	12.8±1.3	17.8±1.3	25.0±0.9	33.4±2.0	50.3±3.7	65.3±4.5	76.1±3.9	88.2±1.3
45°C	4.8±2.0	13.0±3.4	23.1±4.3	38.8±4.7	52.3±4.0	63.7±4.8	72.5±3.7	82.9±3.7	89.2±3.8	93.6±3.9	98.7±3.7
60°C	22.3±4.3	49.6±3.5	64.2±1.9	74.7±0.8	81.4±1.6	85.7±1.5	87.8±1.2	90.9±1.1	-	-	-
1.5% salt											
30°C	2.7±1.1	6.1±1.7	9.7±1.7	14.4±2.7	20.0±4.0	27.1±5.7	35.9±5.7	53.8±7.1	69.3±7.7	79.2±6.2	91.1±3.5
45°C	8.1±1.9	17.3±3.8	29.6±6.4	42.2±7.8	58.4±8.9	70.9±7.5	79.8±5.1	89.1±1.8	94.1±2.2	97.4±3.4	101.2±4.4
60°C	21.7±5.6	48.3±0.8	64.7±4.0	73.3±4.5	80.3±4.3	85.1±3.5	88.3±2.6	92.0±1.9	-	-	-

*average of three determinations

Table 5. Hydration kinetics of beans soaked in sodium chloride and sodium bicarbonate solution.

Exp. No.	Time of soaking (min.)										
	7.5	22.5	37.5	52.5	67.5	82.5	97.5	120	150	180	225
1	5.2±1.1	12.2±1.8	20.9±0.2	34.2±3.2	47.7±6.1	60.0±6.7	70.3±8.3	80.7±6.1	85.2±4.5	88.2±3.7	91.9±2.9
2	4.5±1.4	11.5±1.6	20.8±3.7	32.5±3.0	44.3±3.9	55.5±2.9	66.2±2.8	78.4±1.4	84.5±1.2	87.3±1.1	91.0±1.1
3	4.6±2.0	12.3±3.9	22.4±4.3	35.7±3.7	50.2±2.2	63.2±1.5	73.9±4.2	84.3±5.7	89.7±4.7	93.4±4.1	97.1±3.5
4	3.4±1.0	9.6±2.1	18.6±3.9	30.7±4.6	43.2±7.3	53.7±8.3	64.0±8.8	77.8±6.3	85.6±3.9	90.1±2.2	94.6±1.3
5	1.3±0.4	3.0±1.1	5.5±1.8	8.3±2.2	12.4±3.1	17.3±4.5	23.1±4.7	38.1±5.4	54.7±5.1	69.9±4.8	87.9±5.1
6	1.6±0.7	4.9±1.4	9.5±2.2	17.6±1.8	25.1±3.2	35.9±1.9	48.1±2.5	60.4±3.1	68.4±4.1	74.2±4.2	81.4±3.6
7	12.8±2.4	41.5±2.9	65.8±1.4	78.9±2.4	83.3±4.9	87.9±2.3	80.2±3.0	43.0±5.9	60.7±6.0	73.2±3.4	86.2±0.6
8	10.4±1.1	27.1±2.4	46.0±2.7	59.3±3.1	68.6±3.5	75.9±3.3	27.1±5.5	59.8±5.6	68.1±5.9	74.2±5.7	82.1±4.9
9	1.2±0.1	3.2±0.4	5.9±0.6	9.6±1.2	14.1±1.9	19.9±4.2	46.3±3.9	84.0±2.7	84.5±2.5	86.0±3.6	94.5±1.5
10	2.1±0.9	5.2±1.4	9.2±1.5	16.9±0.8	27.0±0.7	36.3±2.7	84.0±2.7	84.5±2.5	86.0±3.6	94.5±1.5	96.3±2.4
11	12.1±1.8	39.4±6.2	58.3±4.4	71.1±3.8	78.7±2.7	84.0±2.7	84.5±2.5	86.0±3.6	94.5±1.5	96.3±2.4	99.4±4.5
12	12.4±2.5	35.5±0.8	56.4±1.1	68.2±3.2	75.7±4.4	82.2±3.1	84.5±2.5	86.0±3.6	94.5±1.5	96.3±2.4	99.4±4.5
13	2.3±0.4	7.5±0.7	16.3±2.5	28.6±2.1	43.7±0.8	56.5±2.6	67.8±3.1	79.3±3.9	86.0±3.6	90.2±2.5	94.5±1.5
14	4.4±1.4	12.7±1.3	23.7±4.7	42.0±3.9	57.7±2.6	70.5±2.4	78.3±2.3	87.2±2.5	91.2±2.4	93.6±2.2	96.3±2.4
15	6.0±1.9	14.8±2.4	27.0±3.0	41.0±2.9	54.4±1.4	68.0±3.3	76.5±4.3	84.6±5.4	88.7±5.4	91.1±4.8	93.4±4.5
16	7.8±7.3	18.6±17.2	30.8±23.6	42.3±23.3	54.4±19.7	66.3±13.4	76.5±7.3	87.4±1.3	86.7±2.3	88.7±5.4	93.4±4.5
17	11.3±5.9	28.2±12.6	47.0±13.2	60.3±9.7	70.5±5.9	78.3±3.6	82.4±2.8	86.7±2.3	88.7±5.4	91.1±4.8	93.4±4.5

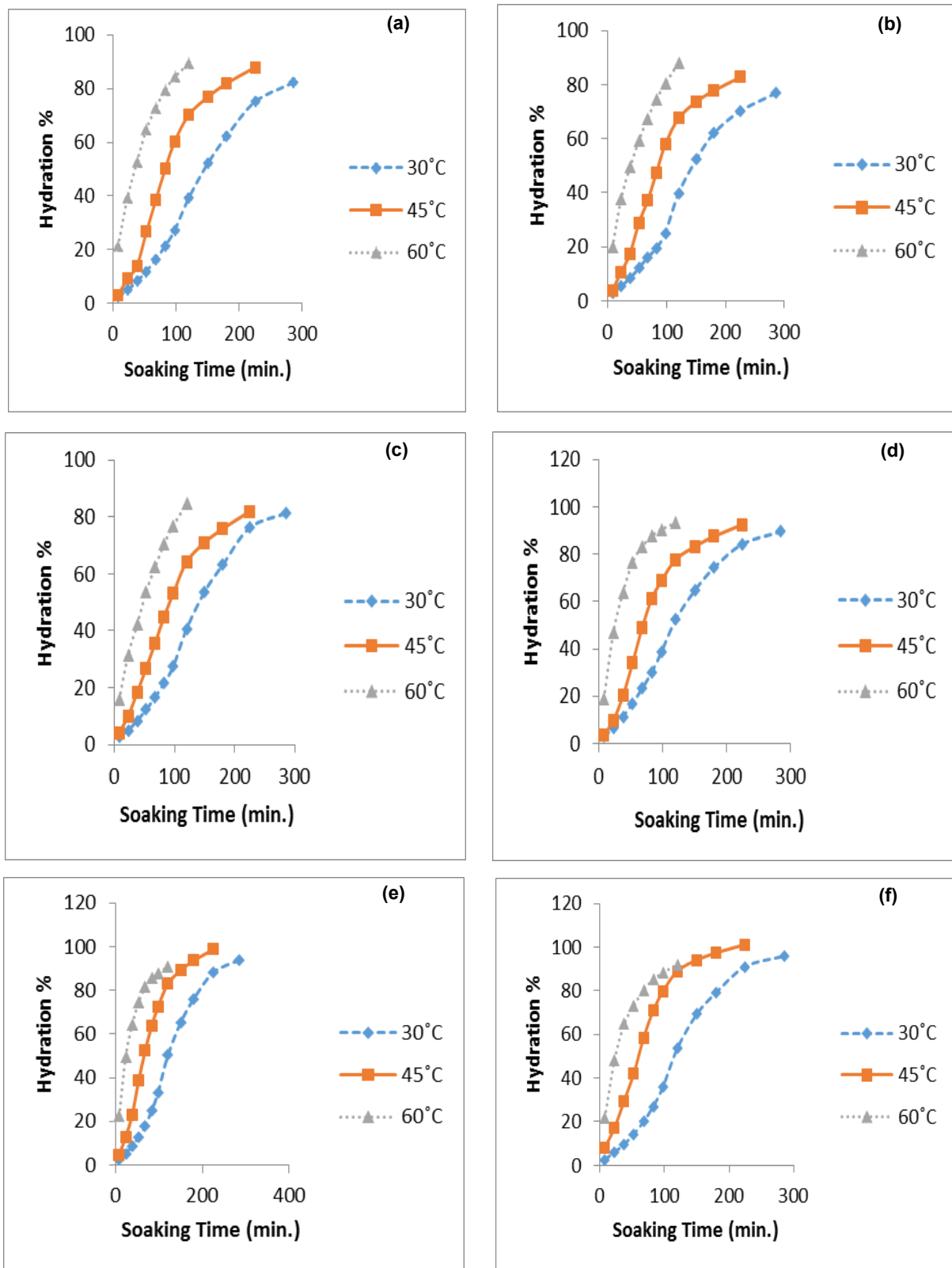


Fig. 1. Effect of temperature on soaking in (a) 0.5% NaCl solution, (b) 1.0% NaCl solution, (c) 1.5% NaCl solution, (d) 0.5% NaHCO₃ solution, (e) 1.0% NaHCO₃ solution and (f) 1.5% NaHCO₃ solution.

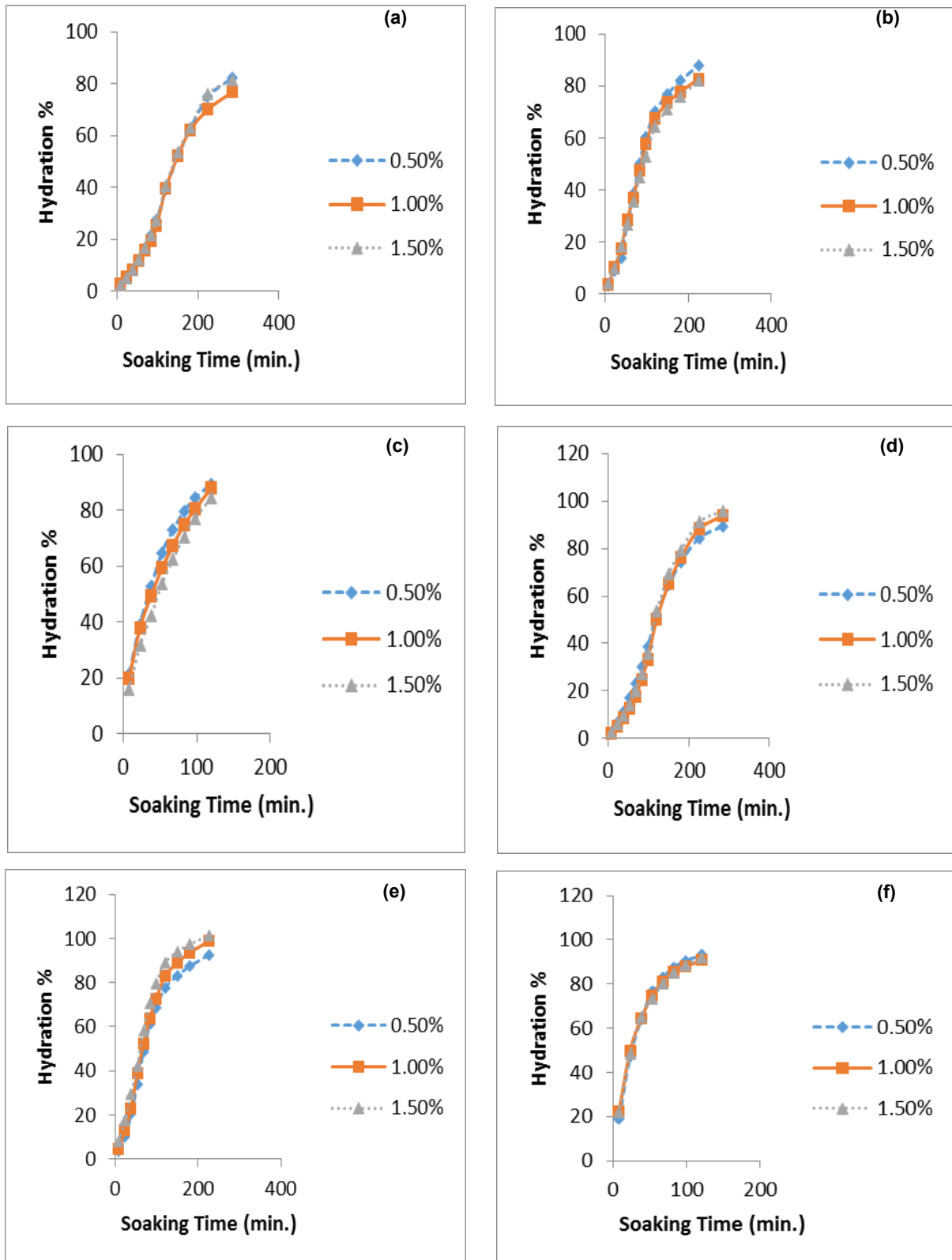


Fig. 2. Effect of NaCl concentration on hydration rate at temperatures (a) 30°C (b) 45°C (c) 60°C and effect of NaHCO₃ concentration at temperatures (d) 30°C (e) 45°C (f) 60°C.

Table 6. Regression Analysis of the relationship between hydration time and hydration rate of beans when regression equation : $y = ax^b$.

Treatment	Soaking temperature (°C)	Regression constants	R ²
Control	30	0.34, 1.00	0.967
	45	1.88, 0.74	0.953
	60	9.47, 0.49	0.982
0.5% NaCl	30	0.27, 1.03	0.97
	45	1.52, 0.77	0.94
	60	8.91, 0.49	0.989
1.0% NaCl	30	0.30, 0.99	0.96
	45	1.80, 0.73	0.95
	60	7.59, 0.52	0.998
1.5% NaCl	30	0.29, 1.01	0.968
	45	1.57, 0.75	0.964
	60	4.98, 0.59	0.998
0.5% NaHCO ₃	30	0.68, 0.88	0.964
	45	2.58, 0.68	0.928
	60	11.99, 0.45	0.943
1.0% NaHCO ₃	30	0.36, 1.00	0.955
	45	2.97, 0.67	0.939
	60	13.8, 0.41	0.945
1.5% NaHCO ₃	30	0.46, 0.97	0.953
	45	4.32, 0.60	0.929
	60	13.04, 0.42	0.958

Table 7. Regression Analysis of the relationship between hydration time and hydration rate of beans when regression equation : $y = ax^b$.

Treatments*	Regression constants	R ²	Hydration time**
-1, -1, 0	2.76, 0.67	0.925	150.72
+1, -1, 0	2.34, 0.69	0.936	156.64
-1,+1, 0	2.83, 0.68	0.927	136.23
+1,+1, 0	1.79, 0.75	0.945	153.797
-1, 0, -1	0.03, 1.50	0.989	204.86
+1, 0, -1	0.58, 0.93	0.952	197.26
-1, 0, +1	6.41, 0.61	0.945	62.64
+1, 0, +1	3.57, 0.69	0.981	89.98
0, -1, -1	0.06, 1.36	0.898	202.15
0, +1, -1	1.08, 0.79	0.935	221.98
0, -1, +1	5.42, 0.63	0.969	69.88
0, +1, +1	6.04, 0.59	0.963	79.17
0, 0, 0	1.76, 0.76	0.926	152.1
0, 0, 0	3.86, 0.62	0.902	132.65
0, 0, 0	4.11, 0.60	0.914	138.44
0, 0, 0	1.23, 0.89	0.997	105.34
0, 0, 0	4.89, 0.62	0.968	93.42

*-1,0, +1 are the coded levels of variables x_1 (NaCl concentration) , x_2 (NaHCO₃ concentration), x_3 (Temperature), **Hydration time for 80% hydration

in 1.10 percent sodium chloride and 0.92 percent sodium bicarbonate resulted in a minimum soaking time of 193.45 min.

Table 8. Results of the regression analysis showing effect of sodium chloride, sodium bicarbonate and temperature on hydration time of the beans.

Factor	Coefficient Estimate	p-value
Intercept	124.39	0.003**
X ₁	5.40	0.46
X ₂	1.47	0.84
X ₃	-65.57	<0.001**
X ₁ X ₂	2.91	0.78
X ₁ X ₃	8.74	0.40
X ₂ X ₃	-2.63	0.80
X ₁ ²	10.17	0.32
X ₂ ²	14.78	0.17
X ₃ ²	4.12	0.68
R ² (%)	93.10	
F-value	10.50	
Lack of fit	Ns	

**Significant at 1% level of significance; ns – non-significant; X₁: sodium chloride conc., X₂: sodium bicarbonate conc., X₃: Temperature

Conclusion

In the present study, RSM was used to optimize the soaking time and soaking treatments for kidney beans to enhance the hydration process. The optimal values were obtained for responses by solving the regression equations of independent variables using Design-Expert software. The water absorption of beans (*Phaseolus vulgaris* L.) increased with time and temperature. It is also affected by the type of salt and its concentration in soaking solution. Soaking in sodium chloride, sodium bicarbonate or ammonium carbonate solution at an elevated temperature decreased the hydration time while an increase in concentration increased the hydration time. The effect of increasing temperature was significant (60 °C), but the effect of salts (1.5%) was insignificant on hydration time in mixed salt solutions of sodium chloride and sodium bicarbonate. The optimum soaking treatment was found to be in a salt solution containing 1.10% NaCl and 0.92% NaHCO₃ at 30°C resulted in a soaking time of 193.45 min.

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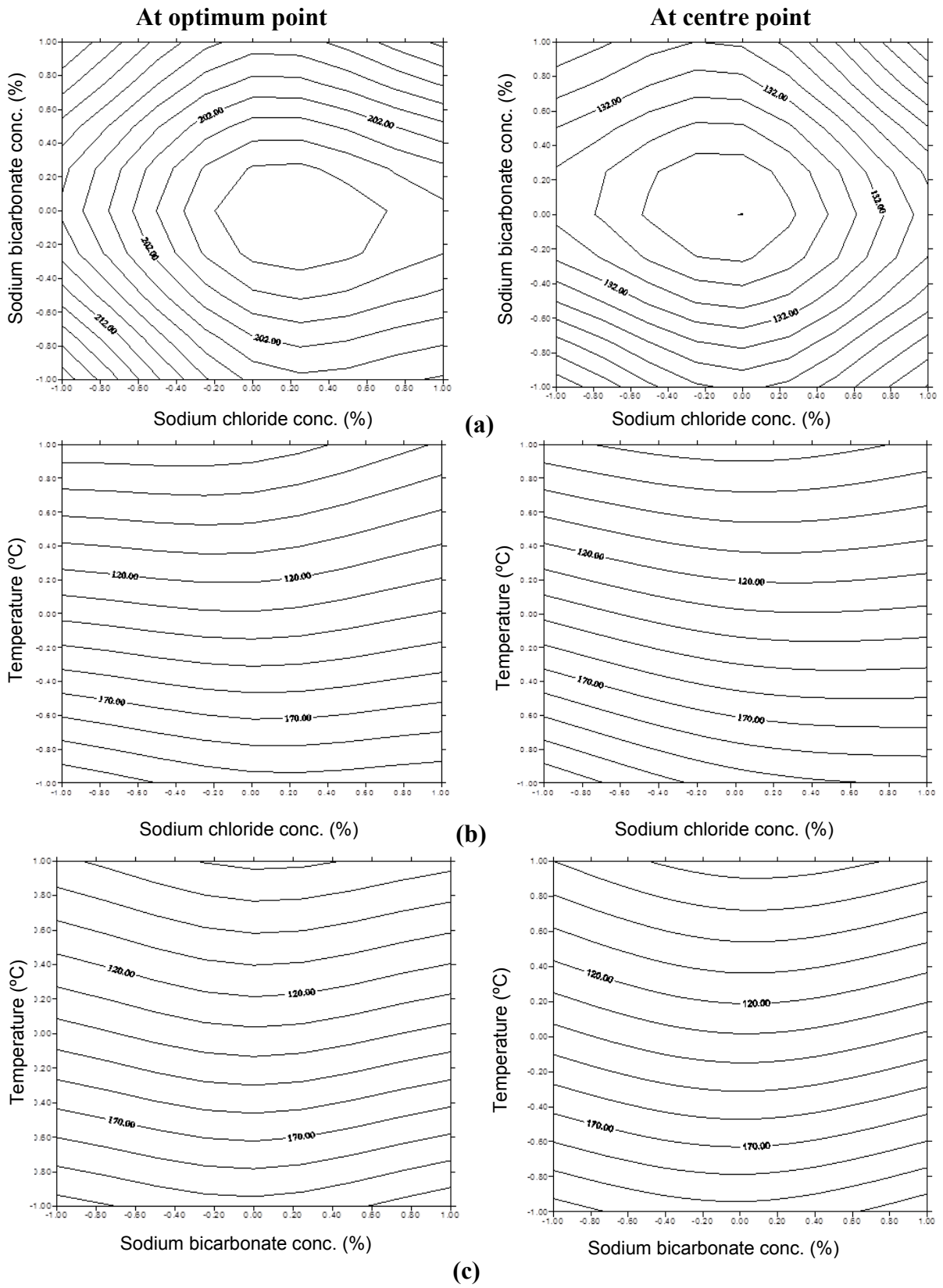


Fig. 3. Contour plots showing effect of sodium chloride, sodium bicarbonate and temperature on hydration time.

Table 9. ANOVA showing effect of sodium chloride, sodium bicarbonate and temperature on hydration time.

Source	Degree of freedom	Sequential sum of squares	Mean square	F-value
Model	9	36570.93	4063.44	10.50**
Linear	3	34648.96	11549.65	32.42**
Quadratic	3	1555.09	518.36	0.3365
Interactive	3	366.89	122.30	0.8339
Error	4	2355.52	588.88	

**Significant at 1% level of significance

Table 10. Individual effect of variables on hydration time.

Variables	Total sequential sum of squares	Average Sequential sum of squares	F-value
NaCl conc. (%)	1008.46	252.12	266.96
NaHCO ₃ conc. (%)	999.26	249.81	264.53
Temperature (°C)	34802.5	8700.63	9213

Table 11. Optimized levels of variables (coded and uncoded).

Variables	Levels	Hydration time
Sodium chloride (%)	0.19 (1.10 %)	193.45 min
Sodium bicarbonate (%)	-0.16 (0.92 %)	
Temperature (°C)	-1.00 (30°C)	

*values in parentheses are the uncoded levels of variables

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