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Application of Statistical Experimental Design to Improve the Quality of Fresh-Cut Apple Cubes by Edible Coating with Alginate

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Abstract The effect of alginate coating in combination with an anti-browning agent on increasing the post-cutting shelf life and improving the quality of minimally processed apple cubes was studied during storage at room temperature for 5 days. A simple coating technique involving the chemical cross-linkage of alginate by calcium was used. Statistical-based experimental designs were applied to improve the quality of the alginate-coated apple cubes (ACAC). Plackett-Burman design was first used to determine the main factors influencing the preservation of the original weight, color, and texture of ACAC. Among these variables, alginate concentration (X_1), dipping time (X_2), and dipping temperature (X_3) significantly influenced the ACAC weight and color (confidence levels above 90%). Subsequently, the effects of the 3 main factors were further investigated by a central composite design. The polynomial models developed by response surface methodology were adequate to describe the relationships between the studied factors and the responses. Overall optimization conducted by superimposing the curves of the responses enabled the determination of an optimal range of the independent variables in which the five responses were simultaneously optimized. The point chosen as representative of this optimal area corresponded to X_1=2.98%, X_2=0.85 min, and X_3=55°C and under these conditions the model predicted weight loss=0.522%, relative hardness=1.517, ΔE=1.423, browning inhibition=93.403%, and ΔL=0.158.

Keywords: apple cubes, alginate coating, Plackett-Burman design, response surface methodology, quality, optimization

Introduction

Fresh-cut fruits and vegetables (FCFV) are becoming more popular to consumers and important in the food supply because of their convenience of use, fresh-like quality, and nutritional availability. The demands for FCFV have increased the quantity and variety of products available to consumers worldwide. Despite their convenience, even the minimal process of cutting poses many limitations to the products' post-cutting shelf life due to undesirable physiological changes, water loss, softening, microbial contamination, surface browning, and increased respiration (1-5).

Many techniques have been employed to minimize the detrimental effects of minimal processing, including refrigeration, controlled (modified) atmosphere packaging, use of additives, and edible coatings (6). Application of edible coatings to minimize undesirable changes due to minimal processing extends shelf life and improve appearance (7). The main advantages attributed to edible coatings are reduced environmental pollution, improved sensorial characteristics of packaged foods (such as color and taste), decreased moisture loss and increased nutritional value of the foods (8). Edible coatings retarded moisture loss by providing a barrier to water vapor, which significantly increased the crispness. Edible coatings can also decrease the russet spotting (browning) and to a lesser extent reduce the loss of total ascorbic acid. They can also reduce respiration and prolong the product shelf-life (5, 9, 10). Since edible coatings offer a semi-permeable barrier against oxygen, carbon dioxide (CO_2), moisture, and solute movement, they can be used to reduce respiration, water loss, and oxidation reaction rates (11).

Alginates are known as a potential biopolymer film or coating component due to their unique and well studied colloidal properties, which include thickening, stabilizing, suspending, film forming, gel producing, and emulsion stabilizing (8, 12). The most useful and unique property of alginates is their ability to react with polyvalent metal cations, specifically calcium ions, to produce strong gels or low soluble polymer (12, 13). The crosslinking with polyvalent cations can improve film characteristics like water resistance, mechanical resistance, barrier properties, cohesiveness, and rigidity (8).

Alginate film is thermo-stable, biodegradable and edible. It will not melt upon frying or cooking and can be easily removed by washing. The film not only reduces transpiration and evaporation, but also controls respiration and maintains a modulated atmosphere around individual pieces of produce from the initial stages after harvest, through transport, storage, and marketing (14). Sodium-alginate and gellan-based coatings have been investigated by many researchers. Ingredients which have been found naturally in garlic skin (such as β-sitosterol) or ones chemically similar to these natural ingredients, can be incorporated into the gum solution before coating to improve film adhesion. Adhesion strengths were about 25 % higher than those recorded for a film made of gum and cross-linking agent alone (15, 16). In addition, calcium can be used to maintain the cell wall structure of vegetables by interacting with pectin to form calcium pectate and it has been reported to maintain firmness by cross-linking with both the cell wall and middle lamella pectin (13, 17). Calcium ions generally form a strong, water-insoluble gel with sodium-alginate, enhancing the water resistance of the alginate film (18, 19).

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Heat treatment has been recently applied as an environmentally friendly method for prolonging the shelf life of minimally processed products (20-22). It can be used to control insect pests, prevent fungal decay, inhibit browning, and improve the textural properties of plants after harvest without using chemicals (3, 17, 23, 24). A previous study indicated that 45 or 55°C hot water treatment was the most effective in reducing apple cube browning (3). In addition, heat-shock treatments, either alone or combined with other agents such as calcium and chlorine, have also been used to prevent browning, reactions and maintain texture in various vegetables and fruits. Firmness increased with heat treatments alone or combined with calcium treatments have been attributed to the action of heat-activated pectin methyl esterase (PME) and/or to increased calcium diffusion into tissues at higher temperatures (17, 25, 26).

The objective of this work was to develop the procedures of alginate coating in combination with ascorbic acid as an anti-browning agent, $CaCl_2$, and β-sitosterol to improve the quality of minimally processed apple cubes by statistical-based experimental designs. Plackett-Burman design was first used to determine the effects of 6 possible process variables (sodium alginate, $CaCl_2$, β-sitosterol, ascorbic acid, dipping time, and temperature) on maintaining the original weight, color, and texture of apple cubes.

Materials and Methods

Materials *Fuji* (*Malus domestica* B.) apples (harvested in Andong, Gyeongbuk; ca. 87 mm in diameter; ca. 11.5 °Bx; ca. 300 g) were purchased from a local supermarket in 20 kg lots and air-stored for 2 weeks at 4°C prior to experiments. Sodium alginate, $CaCl_2$, β-sitosterol, and ascorbic acid were of reagent grade.

Treatment and storage conditions Apples were randomly selected and washed with chlorinated water (125 ppm of active chlorine for 5 min). After peeling and coring, each apple was cut into uniform cubes of 1.5 cm and then immersed in the sodium alginate solution, and mixed with β-sitosterol and ascorbic acid. Residual alginate was then allowed to drip off, before the apple cubes were immersed in a solution of $CaCl_2$ for about 30 sec to induce a spontaneous cross-linking reaction with alginate. Following gelation, the apple cubes were dried and then stored in LDPE bags without sealing in the dark at room temperature for 5 days.

Experimental design and data analysis ***Plackett-Burman experimental design***: The experimental design matrix for screening of those factors deemed to be relative important in maintaining the weight, color, and texture of the apple cubes is shown in Table 1. The total number of experiments to be carried out according to Plackett-Burman is K+1, where K is the number of variables (additives and environmental factors). Each variable is represented by two levels: high (+) and low (−). The number of positive signs is equal to (K+1)/2 and the number of negative signs is equal to (K-1)/2. The choice of the first row is arbitrary, which should contain (K+1)/2 positive signs and (K-1)/2 negative signs. The next (K-1) rows were generated by shifting cyclically one place (K-1) times and the last row contains all the negative signs. Seven variables (with one dummy variable) were screened in 8 experiments (27).

The rows in Table 1 represent the 8 different experiments and each column represents a different variable. The low levels of the design variables were varied by 50% from the respective high variable level, except for X_3 which was only varied by 20%. All the variables, together with the high (+) and low (−) levels of the experimental design, are listed in Table 2. All experiments were performed in duplicate and the average of the weight loss percentage, total color difference and relative hardness were taken as the response.

Statistical analyses were conducted to identify factors that had a significant effect, either positively or negatively (28, 29). The effect of each variable was determined with the following equation:

$$E_{(xi)} = (\Sigma M_{i+} - \Sigma M_{i-})/N$$

where, $E_{(xi)}$ is the concentration effect of the tested variable, M_{i+} and M_{i-} can be the weight loss, total color

Table 1. Plackett-Burman experimental design matrix for the study of 7 factors with 8 experiments

Experiments	Factors							Response		
	X_1	X_2	X_3	X_4	X_5	X_6	$X_7$1)	Weight loss (%)	Relative hardness	ΔE
1	+2)	+	+	−	+	−	−	3.00	1.195	4.92
2	−3)	+	+	+	−	+	−	9.80	1.248	4.65
3	−	−	+	+	+	−	+	13.10	1.178	5.55
4	+	−	−	+	+	+	−	3.40	1.322	2.77
5	−	+	−	−	+	+	+	7.30	1.266	3.65
6	+	−	+	−	−	+	+	4.60	1.008	7.39
7	+	+	−	+	−	−	+	3.90	0.729	9.39
8	−	−	−	−	−	−	−	7.60	0.990	10.37

1)The factor, X_7 is designated as 'dummy variable'.
2)+: Higher level; 3)-: Lower level.

Table 2. The relationship between the coded levels and the actual levels of 7 factors

Factors	Levels		Unit
	+	-	
X_1: Alginate	2	1	%
X_2: $CaCl_2$	2	1	%
X_3 : β-Sitosterol	0.05	0.01	%
X_4: Ascorbic acid	1	0.5	%
X_5: Dipping temperature	50	25	°C
X_6: Dipping time	2	1	min
X_7: Dummy variable	-	-	-

difference, and relative hardness of the apple cubes where the variable (X_i) measured was present at high and low levels, respectively, and N is the number of experiments (8 in this case).

Experimental error was estimated by calculating the variance among the dummy variable as follows:

$$V_{eff}=\Sigma(E_d)^2/n$$

where, V_{eff} is the variance of the concentration effect, E_d the concentration effect for the dummy variable, and n is the number of dummy variables used. The standard error (SE) of the concentration effect was the square root of the concentration:

$$SE=\sqrt{\frac{\Sigma(E_d)^2}{n}}$$

and the p-value (significance level) of each concentration effect was determined using Student's t-test to compare the actual difference between two means in relation to the variation in data, expressed as the standard deviation of the difference between the means:

$$t_{(xi)} = E_{(xi)}/SE$$

where, $t_{(xi)}$ is the t-value of each variable and $E_{(xi)}$ the effect of variable X_i (27, 30). The variables with confidence levels greater than 90% were considered to have significantly influenced the quality of the apple cubes.

Optimization of the screened factors: Response surface methodology (RSM), a central composite design (CCD), was used to optimize the screened factors (identified by Plackett-Burman) in order to enhance the apple cube quality. According to CCD, the total number of the treatment combinations was 2^k+2k+n_0, where k is the number of independent variables and n_0 the treatment of repetition of the experiment at the center point (31, 32).

For statistical calculations, the variables X_i were coded as x_i according to the following equation:

$$x_i=\frac{X_i-X_0}{\Delta X},\ i=1, 2, 3,\ldots, j$$

where, x_i is the dimensionless coded value of the variable X_i, X_i the real value of the independent variable, X_0 the value of X_i at the center point, and ΔX the step change value.

The levels of three independent variables, alginate (A), dipping time (B), and dipping temperature (C), were optimized by the experimental design. Each factor in the design was studied at five different levels (-α, -1, 0, +1, +α) (Table 3). A set of 20 experiments was carried out and all variables were taken at a central coded value considered as zero.

Upon completion of the experiments, the average percentage weight loss, total color difference, percentage browning inhibition, ΔL, and relative hardness (N) were taken as the response (Y), respectively. A second order polynomial equation was then fitted to the data by a multiple regression procedure to produce an empirical model that related the response measured to the independent variables of the experiment. For a three-factor system the model equation is:

$$Y=\beta_0+\sum_{i=1}^{3}\beta_i x_i+\sum_{i\neq j=1}^{3}\beta_{ij}x_i x_j+\sum_{i=1}^{3}\beta_{ii}x_i^2$$

where, Y is the response variable, β_0 the intercept, β_i the coefficients for the linear, β_{ii} the coefficients for the quadratic effect, and β_{ij} the coefficients for the interaction effect.

The above equation was solved using the SAS package (33) to estimate the responses of the dependent variables (27, 34-36), and the contour plots were generated.

Analytical methods ***Weight loss***: Weight loss was calculated by weighing 10 apple cubes per replicate, and expressed as the percent loss from the initial fresh weight.

Table 3. Independent variables and the levels studied in central composite design

Variable	Factors	Range studied	Levels of variables				
			$-\alpha^{1)}$	$-1^{2)}$	$0^{3)}$	1	+α
A	Sodium alginate	0.318-3.682 (%)	0.318	1	2	3	3.682
B	Dipping time	0.318-3.682 (min)	0.318	1	2	3	3.682
C	Dipping temperature	40-60 (°C)	40	45	50	55	60

$^{1)}$-α, +α = Lowest and highest value in the range studied for each variable;
$^{2)}$-1, +1 = Intermediate value between the central and extreme levels of each variable;
$^{3)}$0 = Central level in the range studied for each variable.

Color assessment: Color of apple cubes was evaluated using a colorimeter (Model CR-200; Minolta Co., Osaka, Japan) calibrated with a white standard ($Y = 94.2$, $x = 0.3131$, $y = 0.3201$), and reported as CIE L, a, and b values. Measurements of 10 samples per treatment were individually taken, and mean values were compared. The individual readings in L, a, and b values at time t and zero were combined to obtain the total color difference (ΔE) using the following equation:

$$\Delta E = [(L_0-L_t)^2+(a_0-a_t)^2+(b_0-b_t)^2]^{0.5}$$

where, L_0, a_0, and b_0 represent the readings at zero time, and L_t, a_t, and b_t represent the readings at each time interval for the treatment. A large ΔE denotes greater color change from the initial ones.

The percent inhibition of browning is expressed as follows (37):

$$\text{Browning inhibition (\%)} = (\Delta a_{\text{control}} - \Delta a_{\text{treatment}}) / \Delta a_{\text{control}} \times 100$$

where, Δa is the difference between a value at time t and zero.

Texture assessment: Texture characteristics were evaluated by 30% compression of the apple cubes with a computer-controlled, Advanced Universal Testing System (model LRX*Plus*; Lloyd Instrument Limited, Fareham, Hampshire, UK) at room temperature. A 100-Newton (N) load cell was used, with a crosshead speed of 10 mm/min. A 5-mm diameter, stainless steel cylinder probe was used. Relative hardness of the treated apple cube was determined after 5 days with respect to the untreated apple cube according to the following expression:

$$\text{Relative hardness} = (F_2-F_1)/F_1$$

where, F_1 and F_2 are the maximum compression force (N) of the untreated and treated apples, respectively (38).

Results and Discussion

Screening of the variables The Plackett-Burman experimental plan and corresponding results are shown in Table 1. The design included 8 experiments and 2 levels for each factor. The factors designated X_1 to X_6 represent process conditions, while X_7 is the dummy variable. A positive and negative concentration effect, $E_{(xi)}$, of the tested variable indicates that the influence of the variable is greater at a high and a low concentration, respectively (21).

Variable weight: Table 4 presents the results of screening experiments for improving the quality of alginate-coated apple cubes (ACAC). The $E_{(xi)}$ values of variables X_1 (alginate), X_2 ($CaCl_2$), and X_6 (dipping time) were negative at -2.863, -0.588, and -0.313, while X_3 (β-sitosterol), X_4 (ascorbic acid), and X_5 (dipping temperature) were positive at 1.038, 0.963, and 0.113, respectively. Therefore, the influences of X_3, X_4, and X_5 on apple cube weight loss were greater at a high level, while those of X_1, X_2, and X_6 were greater at a low level. The significance of each variable was determined by applying the student's t-test (28). Among them, X_1 had a confidence level above 90% and was considered to significantly influence the ACAC weight.

Table 4. Results of screening experiments for improving the quality of alginate-coated apple cubes

Reponses	Variables	E_{xi}	$t_{(xi)}$	Prob.>|t|	Confidence level (%)
Weight loss	X_1	-2.863	-4.490	0.0698	93.02
	X_2	-0.588	-0.922	0.2630	73.70
	X_3	1.038	1.627	0.1754	82.46
	X_4	0.963	1.510	0.1862	81.38
	X_5	0.113	0.176	0.4444	55.56
	X_6	-0.313	-0.490	0.3549	64.51
Relative hardness	X_1	-0.053	-0.744	0.2963	70.37
	X_2	-0.007	-0.104	0.4671	53.29
	X_3	0.040	0.561	0.3373	66.27
	X_4	0.002	0.034	0.4891	51.09
	X_5	0.123	1.719	0.1677	83.23
	X_6	0.094	1.312	0.2073	79.27
Total color difference	X_1	0.031	0.076	0.4760	52.40
	X_2	-0.434	-1.063	0.2402	75.98
	X_3	-0.459	-1.125	0.2313	76.87
	X_4	-0.495	-1.215	0.2192	78.08
	X_5	-1.863	-4.569	0.0686	93.14
	X_6	-1.473	-3.613	0.0859	91.41

Variable texture: The effect of each variable on apple cube relative hardness is also shown in Table 4. The $E_{(xi)}$ values of variables X_1 (alginate) and X_2 ($CaCl_2$) were negative at -0.053, and -0.007, while X_3 (β-sitosterol), X_4 (ascorbic acid), X_5 (dipping temperature), and X_6 (dipping time) were positive at 0.040, 0.002, 0.123, and 0.094, respectively. The influences of X_3, X_4, X_5, and X_6 were greater at a high value, while those of X_1 and X_2 were greater at a low value. However, according to student's t-test, the confidence levels of all variables were below 90 %, and hence considered insignificant.

Variable color: As to the total color difference, the $E(xi)$ value of each tested variable (X_1, X_2, X_3, X_4, X_5, X_6) was 0.031, -0.434, -0.459, -0.495, -1.863, and -1.473, respectively. Except for the influence of X_1, which was greater at a high value, the influences of all 5 other tested variables were greater at a low value. In addition, the confidence levels of X_5 and X_6 were above 90%. Therefore, dipping temperature and dipping time were considered to significantly influence the color of ACAC (Table 4).

Effects of screened variables Based on the Plackett-Burman design, X_2 ($CaCl_2$), X_3 (β-sitosterol), and X_4 (ascorbic acid) were non-significant (Table 4). Therefore, for the next step of optimization, the non-significant variables were set to their lower level. The variables which showed confidence levels above 90% (alginate, dipping temperature, and time) were selected and optimized using CCD. RSM can be used to model and analyze the situations in which a response of interest is affected by several variables (39). The aim of RSM is to optimize the response and to determine the optimum operating conditions for a system in which operation requirements are satisfied (40). Table 3 shows three operating variables examined in this study and their 5 levels. The factorial design and experimental response values for each experiment are presented in Table 5. Weight loss, relative hardness, ΔE, browning inhibition, and ΔL values were in the range of 0.42-2.82%, 0.815-1.896, 2.08-23.99, 23.87-85.58%, and 0.12-23.41, respectively.

The second order polynomial equations were found by applying multiple regression analysis to the experimental data (Table 6). The coefficient determinations (R^2) were 0.6122, 0.4851, 0.6200, 0.5301, and 0.6013 for weight loss, relative hardness, ΔE, inhibition browning, and ΔL, respectively, and were used as a measure of goodness to fit models. Although the R^2 values were slightly low, the lack of fit was observed to be insignificant, indicating that the adequacy of the models to represent the experimental data.

Table 5. Factorial design and experimental response for alginate-coated apple cubes

Std	Run	A (%)	B (min)	C (°C)	Weight loss (%)	Relative hardness	ΔE	Browning inhibition (%)	ΔL
16	1	2	2	50	1.52	1.663	15.21	61.65	13.88
15	2	2	2	50	1.68	0.874	23.99	39.62	23.41
7	3	1	3	55	0.93	1.311	6.09	70.18	1.97
20	4	2	2	50	1.74	1.191	6.27	80.55	5.22
18	5	2	2	50	2.45	0.815	17.92	44.93	16.23
12	6	2	3.682	50	1.21	1.519	6.64	78.20	2.71
11	7	2	0.318	50	0.86	1.616	9.38	77.82	7.05
6	8	3	1	55	0.47	1.355	2.08	85.58	0.12
2	9	3	1	45	0.81	1.002	8.45	71.24	7.04
14	10	2	2	60	1.57	1.708	4.34	82.16	1.78
4	11	3	3	45	0.42	1.896	9.32	63.57	8.59
13	12	2	2	40	1.34	0.968	4.16	76.53	2.21
8	13	3	3	55	0.47	1.217	4.35	83.45	0.53
1	14	1	1	45	1.42	1.097	17.89	23.87	11.37
17	15	2	2	50	2.82	1.137	18.33	38.06	16.79
10	16	3.682	2	50	0.70	1.588	3.70	83.60	2.85
5	17	1	1	55	0.53	1.149	5.78	66.88	2.15
3	18	1	3	45	0.89	1.183	8.53	64.44	5.70
9	19	0.318	2	50	1.41	0.917	9.30	64.29	5.62
19	20	2	2	50	1.05	0.855	9.85	74.09	5.74

Table 6. Regression models and simplified analysis of variance of process variables of alginate-coated apple cubes

Response[1)]	Fitting model[2)]	LOF[3)]	R^2	F-value	p-value>F[4)]
Y_1	$= -10.9149 + 0.70164A - 0.014150B + 0.50047C - 0.38422A^{2**} - 0.032859AB - 0.39247B^{2**} + 0.01389AC + 0.033079BC - 0.006028C^2$	ns	0.6122	4.63	0.0281**
Y_2	$= 2.34068 + 0.49686A + 0.53937B - 0.1162C + 0.036049A^2 + 0.063599AB + 0.14742B^2 - 0.012647AC - 0.023893BC + 0.00205958C^2$	ns	0.4851	1.15	0.3778
Y_3	$= -208.21737 + 2.80762A - 8.23612B + 9.57587C - 2.89243A^{2*} + 1.52375AB - 2.35772B^2 + 0.07987AC + 0.277BC - 0.10609C^{2**}$	ns	0.6200	3.83	0.0462**
Y_4	$= 340.62314 + 23.3915A^{*} + 33.53319B - 15.25700C + 4.07959A^2 - 6.70784AB + 5.51676B^2 - 0.3634AC - 0.79288BC + 0.18747C^2$	ns	0.5301	1.20	0.3587
Y_5	$= -265.14115 + 12.72771A + 3.69885B + 10.91123C - 3.20923A^{2*} + 0.97625AB - 2.98163B^{2*} - 0.05875AC + 0.10913BC - 0.11388C^{2**}$	ns	0.6013	4.16	0.0374**

[1)] Y_1 = weight loss (%); Y_2 = relative hardness (N); $Y_3 = \Delta E$; Y_4 = Browning inhibition (%); $Y_5 = \Delta L$.
[2)] *A* = alginate (%); *B* = dipping time (min); *C* = dipping temperature (°C).
[3)] LOF = lack of fit test; ns = no significant effect.
[4)] *Significant at $p<0.1$; **Significant at $p<0.05$; ***Significant at $p<0.01$.

ANOVA showed that the predicting models for the five responses had no significant lack of fit (at $p>0.05$), implying that the models represent the data well in the experimental domain or that variations in the models can not be accounted for by random error (39). The mathematical models shown in Table 6 were used to generate surface plots. Predicted values of each response variable can be observed on their respective surface plots (Fig. 1-5).

Optimization With the aim of definitively determining the optimal conditions of ACAC production, an optimization was conducted using the methodology described by Myers and Montgomery (41). Table 7 summarizes the set of optimization criteria for the variables and the outputs of the optimization process.

As shown in Table 7, five different combinations of operation conditions resulted from the optimization, with the ranges X_1=2.95-3.00%, X_2=1.00-1.03 min, and X_3= 54.78-55.00°C being tested to achieve the highest values of browning inhibition (89.25-90.84%) and the lowest values of weight loss (0.623-0.699%), *ΔE* (2.328-2.896), and *ΔL* (1.057-1.605).

From the set of constraints and outputs given in Table 7, contour plots of relevant and statistically significant

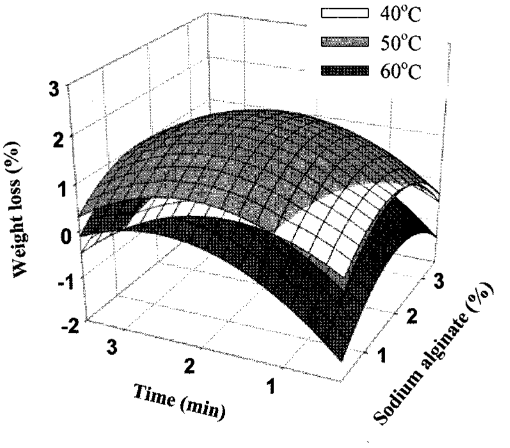

Fig. 1. Response surface plot of weight loss: the effect of alginate, dipping time, and dipping temperature.

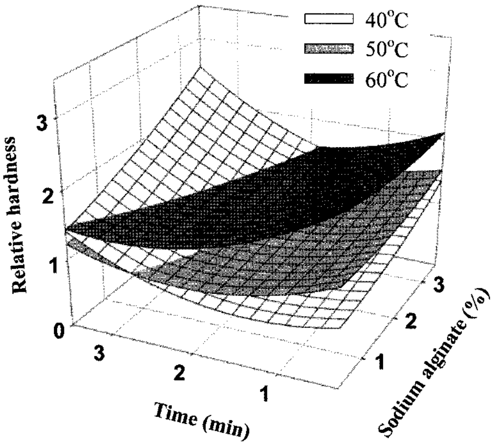

Fig. 2. Response surface plot of relative hardness: the effect of alginate, dipping time, and dipping temperature.

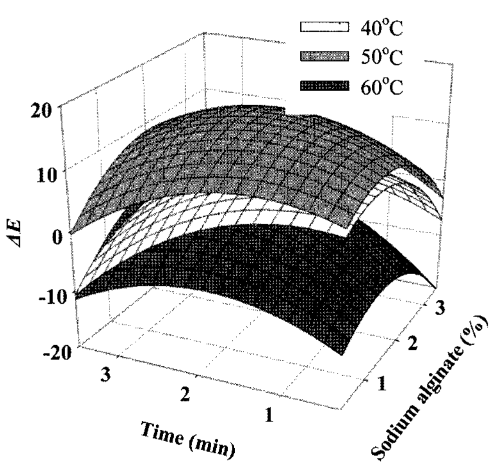

Fig. 3. Response surface plot of *ΔE*: the effect of alginate, dipping time, and dipping temperature.

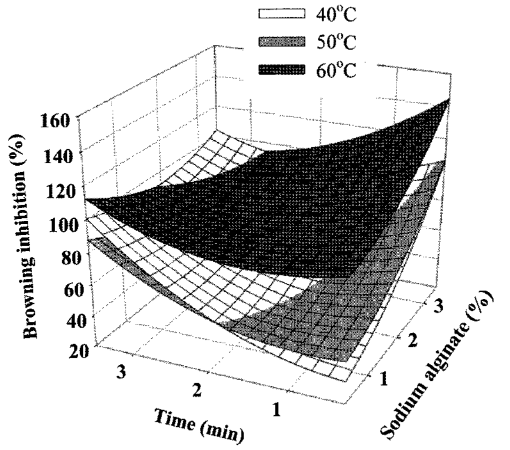

Fig. 4. Response surface plot of browning inhibition: the effect of alginate, dipping time, and dipping temperature.

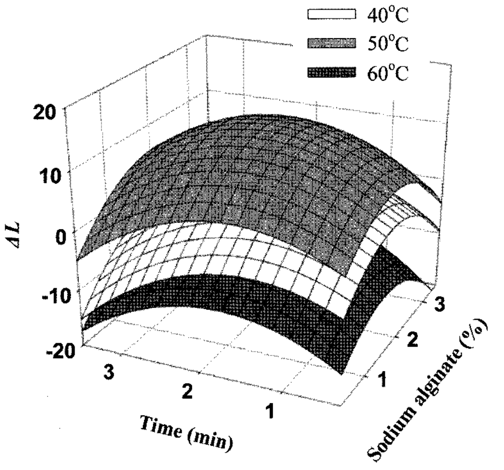

Fig. 5. Response surface plot of *ΔL*: the effect of alginate, dipping time, and dipping temperature.

Table 7. Criteria and outputs of the numerical optimization

Criteria	Goal	Limit
X_1: Sodium alginate (%)	In the range	1-3
X_2: Dipping time (min)	In the range	1-3
X_3: Dipping temperature (°C)	In the range	45-55
Y_1: Weight loss (%)	Minimize	0-1
Y_2: Relative hardness	In the range	0.815-1.899
Y_3: ΔE	Minimize	0-3
Y_4: *Browning inhibition (%)*	Maximize	80-100
Y_5: ΔL	Minimize	0-2

Outputs

No.	X_1	X_2	X_3	Y_1	Y_2	Y_3	Y_4	Y_5
1	3	1.00	55.00	0.623	1.472	2.328	90.844	1.057
2	3	1.03	55.00	0.647	1.465	2.499	90.363	1.223
3	3	1.00	54.78	0.643	1.461	2.669	90.087	1.416
4	2.95	1.00	55.00	0.665	1.468	2.743	89.818	1.457
5	3	1.00	55.00	0.699	1.448	2.896	89.247	1.605

responses were used to produce superimposed contour plots, as shown in Fig. 6. The constraints values of weight loss (0-1%), relative hardness (0.815-1.899), ΔE (0-3), browning inhibition (80-100%), and ΔL (0-2) delimited a shaded surface which incorporated the 5 outputs of Table 7. Thus, optimum process conditions can be drawn from this delimited area to achieve a specific goal. For example, point A in Fig. 6 determines the following criteria and goals: $X_1 = 2.98\%$, $X_2 = 0.85$ min, and $X_3 = 55°C$ weight loss = 0.522%, relative hardness = 1.517, ΔE = 1.423, browning inhibition = 93.403%, and ΔL = 0.158.

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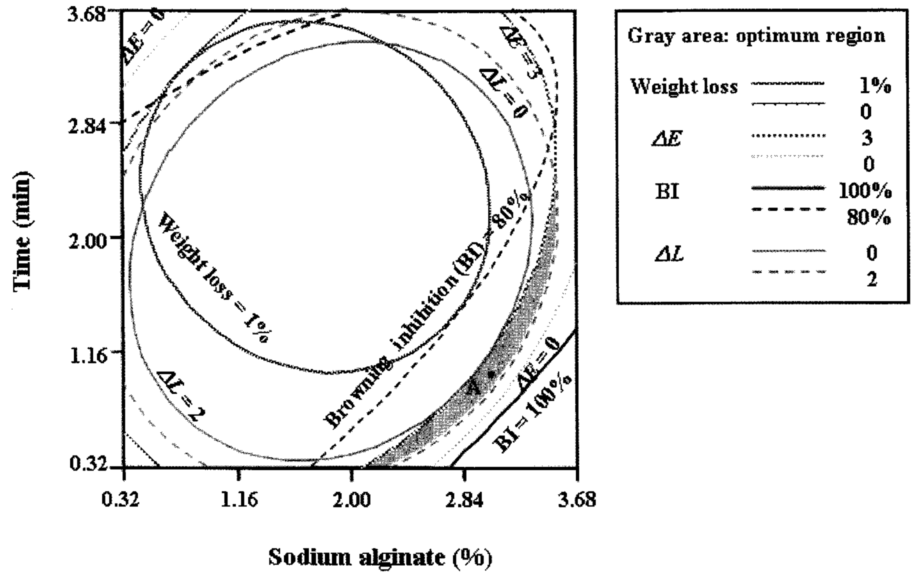

Fig. 6. Superimposed contour plot for optimization of the effect of alginate, dipping time, and dipping temperature.

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