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Optimization of potato starch gel formulation as green alternative of animal-sourced gelatin

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Abstract

This study was aimed at optimization of potato starch gel preparation process by response surface methodology and various process parameters were optimized for textural, gelation and sensory properties. 3D response surface and contour plots showed that independent variables, such as extraction time, extraction temperature and potato starch concentration significantly affected ($p < 0.05$) texture of potato starch gel. It was observed from RSM analysis that target responses regarding texture characteristics (hardness 1, hardness 2, springiness and chewiness) were significantly reliant on potato starch conc. followed by extraction time and temperature. T_o was found in range from 102.98 to 109.87 °C whereas, the mean T_o was maintained at 107.20 °C. It was evident from data of experimental runs that T_o showed relatively consistent tendency in majority of samples while, experimental runs no. 4 and 5 exhibited a maxima and minima of 109.87 °C and 102.98 °C, respectively. It was evident from T_o value that starch granules were subjected to degree of disintegration in its internal granules structure, and this disintegration led to polysaccharides release in surrounding medium.

Keywords: potato starch; response surface methodology; RVA; PSG; functional food; characterization; gelatinization.

Practical Application: Potato starch gel can be used as natural alternative of gelatin.

1 Introduction

Gelatin is a distinctive, multifunctional and innate ingredient which is easily consumable (Brinckmann & Bachinger, 2005). However, the increasing demand for non-mammalian gelatine for halal and kosher food markets have revived interest in gelatine replacers from plant sources (Jaswir et al., 2016). There are many serious issues regarding unlawful and lawful foods which are affecting Muslims in recent times. It can be produced from tubers like potato starch which is halal, cheapest and excellent (Jamróz et al., 2018).

Gels may be defined as the intermediate form of matter between solid and liquid and show mechanical rigidity (Aguilera, 1992). They consist of polymer molecules crosslinked to form tangled and interconnected molecular network immersed in a liquid medium, which in food system is water (Oakenfull & Glicksman, 1987). Food technologists use the word 'gel' for high moisture foods that retain their shape when released from their container. However, the most used definition of gel is a rheological one, obtained from dynamic viscometry. According to this definition, a gel is a viscoelastic system with a 'storage modulus' (G′) larger than the 'loss modulus' (G″) (De Vries, 2004). Hydrocolloids form gels by physical association of their polymer chains through hydrogen bonding, hydrophobic association and cation mediated cross-linking and differ from synthetic polymer gels, which normally consist of covalently cross-linked polymer chains. Hence, hydrocolloid gels are often referred to as "physical gels" (Phillips & Williams, 2000).

Ionotropic gelation occurs via cross-linking of hydrocolloid chains with ions, typically a cation mediated gelation process of negatively charged polysaccharides. Examples of such systems are alginate, carrageenan and pectin (Imeson, 2000; May, 2000). Ionotropic gelation is carried out by either diffusion setting or internal gelation. In cold-set gelation. Potato starch is one of the most common polysaccharides naturally occurring, used as thickeners, stabilizer, binging, emulsifying, and gelling agent (Tolstoguzov, 2002). and an important constituent extensively used in the food industry as a functional texturizer. The mucilaginous polysaccharides are used in pharmaceutical industries as a food thickener, gelling agents, and production of edible films (Kennedy, 1979). Starch is stored in granules and found in cereals like maize, wheat, rice, barley and tubers such as potato and tapioca are particularly rich in starch. Starch is generally composed of two different types of polymers like amylose, a linear molecule consisting almost exclusively of α-1,4-linked glucose residues and another amylopectin which in addition to linear chains of α-1,4-linked glucose also contains α-1,6-linked branch points. When heated in water, causes gelatinization

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produces highly viscous paste. On cooling, gelatinized starch forms a textural gel network if starch concentration has reached a critical concentration. Potato starch is an exclusive among commercial starches in having a high level of phosphate groups that are covalently linked to the C_6 and C_3 positions of the glucose monomers. These phosphate groups, coupled with the large size of the granules, give this starch a very high swelling power and stable paste properties of this starch (Jobling, 2004). Potato starch exhibits higher swelling power, solubility, paste clarity, and viscosity than wheat, rice, and corn starches. Potato starch shows a higher tendency toward retrogradation compared with cereal starches (Singh et al., 2003). For the development of the initial gel network amylose is a key player having a tendency to quickly form connected double-helix aggregates. Amylopectin gelation, on the other hand is a slower process involving weaker reversible chain associations (Kaper et al., 2004). In this study, the manufacturing of potato starch gel was optimized by response surface methodology and various operational parameters were optimized for textural, gelation and sensory properties.

2 Materials and methods

2.1 Sample procurement

Commercial (unmodified) potato starch was obtained from National Starch & Chemical Co. (NJ, USA), KGM (95% purity), TIC organic® Konjac HV (White Marsh, MD, USA) was supplied by Cornell University Food Science Department, Ithaca, USA. Sodium azide (99% extra pure) was purchased. Thermo Fisher Scientific Acro's Organics (Morris, NJ, USA), Lecithin powder was supplied from (Alfa Chem 2 Harbor Way Kings Point, NY, USA) respectively.

2.2 Moisture content

Moisture content of potato starch powders was measured in a hot-air cabinet dryer at Department of Food Science, Cornell University USA. An aliquot of 5 g was weighed precisely and heated for 3 h at 105 °C. Samples were left to cool in a desiccator until room temperature was reached and then weighed. Measurements were performed in triplicate. Moisture content was calculated as follows (Equation 1):

$$MC = \frac{m_i - m_f}{m_i} \times 100 \quad (1)$$

where m_i is the initial mass and m_f is the final mass after drying (Freschi et al., 2014).

2.3 Preparation of potato starch gel

Potato Starch gels were prepared with some modification following (Liu & Xu, 2019). Initially, Potato Starch powder was weighed in different beakers with various concentrations (10, 15, 20, 25 and 30%,w/w) and 0.02% of sodium azide (Gojira Fine Chemicals, Ohio, USA) (to inhibit microorganisms), (0.25, 0.75 and 1% w/w) KGM powder (to control the syneresis in gel) and (0.5%) lecithin power was primarily dissolved thoroughly in deionized water with continuous magnetic stirring for 30 min at room temperature to avoid the formation of starch lump, covered with parafilm to avoid evaporation. Manually shaken until gelation occurred, potato starch mixtures were heated in boiled water for 20, 30, 35, 60 and 72 mins in the bath at temperatures (55, 65, 75, 85, and 95 °C), then with continuous manual stirring for the first 10 min. The paste was poured into a beaker (20 mm in height and 40 mm in diameter) and covered with parafilm to prevent evaporation loss. All samples were then cooled and stored at 4 °C in refrigerator overnight for maturation of gels.

2.4 Determination of potato starch gel pasting characteristics

The pasting properties of the potato starch with KGM were determined using a Rapid Visco-Analyzer Perten (model RVA 4, Newport Scientific, Australia). First KGM was dispersed in 25 mL distilled water with magnetic stirring. For each run, an appropriate amount of potato starch (2.5, 3.0, and 3.5 g) were added slowly to KMG solutions to avoid any lump formation. The slurries were rapidly mixed at 50 °C for 1 min (960 rpm) then pasted while being stirred at 160 rpm.The at a rate of 13 °C/min, held at 95 °C for 3 min, cooled to 50 °C at 13 °C/min and held at 50 °C for 4 min. After detection, peak viscosity (PV), trough viscosity (TV), breakdown viscosity (BV), final viscosity (FV), setback viscosity (SV) as well as pasting temperature (PT) were obtained. All the measurements were done in triplicate (Zhang et al., 2019; Shafie et al., 2016).

2.5 Determination of gel pasting characteristics

A Perten rapid visco analyzer (RVA, Newport Scientific, Australia) was used to record and analyse the pasting properties of the rice flours. Rice flour suspension was prepared by adding 3.00 ± 0.01 g of the flour directly into a metal RVA canister containing 25 mL of distilled water. Paddle was jog up and down to remove any lump that formed. The pasting profile was recorded in triplicate under a constant shear rate (160 rpm) with heating and cooling cycles of 50 °C to 95 °C for 13 min (Association of Official Analytical Chemists, 2000). Peak viscosity (PV), trough/hold viscosity (HV), breakdown (BD), final viscosity (FV), setback (SB), pasting temperature (PT) and peak time were recorded from the RVA curve. Stability ratio was the ratio of hold viscosity to peak viscosity and setback ratio was the ratio of final viscosity to hold viscosity.

2.6 Determination of gel texture characteristics

Texture of potato starch gel was determined in a texture analyzer TA-XT plus, Stable Micro Systems, (Texture Technologies crop., Scarsdale, NY, USA) and property of Cornell university USA. For Experiments were performed 24 h after sample preparation to allow full gel maturation. Before textural testing, samples were equilibrated for about 1h at 25 °C. Each sample container was placed upright on the metal plate, Equipped with a 50 kg cell load, cylindrical probe (P/5), a control force of 5 g was used to compress the gels to 40% of the original height. The test speed of 0.5 mm/s, with a 5 g tiger force to compress the gel twice. From TPA curve Note here that hardness 1 and 2 (peak force of the first cycle), springiness (related to elasticity), and chewiness were determined. The analysis was tested in triplicate (Liu & Xu, 2019).

2.7 Determination of gel texture characteristics

Texture profile analysis (TPA) measurements were conducted on a texture analyser (TA-XT plus, Stable Micro Systems, UK) with a load cell of 5 kg as reported elsewhere. For this purpose, starch gel samples prepared in cylindrical flasks filled up to 80% (4.5 cm height and 2.5 cm diameter) were submitted to a double penetration (compressed) using a cylindrical probe P/05R (0.6 mm radius, 2 mm/s crosshead speed, and 5 mm penetration). Experiments were performed 24 h after sample preparation to allow full gel maturation. Before textural testing, samples were equilibrated for about 1h at 25 °C. Note here that hardness 1 and 2 (peak force of the first cycle), springiness (related to elasticity), and chewiness were determined (Torres et al., 2018).

Determination of gelation characteristics

The gelation parameters were determined by digital scanning colorkmeter with a Shimadzu calorimeter, model DSC-50 (Shimadzu Corp. Tokyo, Japan), These parameters were based on the conventional laboratory program and an appropriate method. Transition temperatures were recorded from a plot of heat flow vs. temperature (30-500 °C). The peak temperature (T_p) of gelatinization was determined from the DSC curve with Shimadzu TASYS software. The reaction heat was determined by using the area of the peaks between the onset temperature (T_0) and the end-temperature from the DSC curve. Samples (2.00 mg) were weighed to the nearest ± 0.01 mg and sealed in aluminium pans. The images were captured by means of DSC coupled to the photo visual system under similar conditions of conventional DSC. Medium and standard deviation values were determined from triplicates of DSC curves. The instrument was calibrated via the melting points of indium (156.6 ± 0.3 °C) and zinc (419.6 ± 0.3 °C) standards. The heat flow and enthalpy were calibrated via the heat of fusion of indium (28.59 ± 0.30 J/g) under the same conditions as for the samples.

2.8 Measurement of thermal properties potato starch gel (DSC)

The experiment was carried out in Food Engineering lab. In Stocking hall Cornell university USA, Differential Scanning Calorimeter (DSC, Mettler-Toledo Inc., Columbus, OH, U.S.A) (Reddy et al., 2015). A starch sample was precisely weighed (2 mg, dry weight: DW basis) and mixed with 7 µL distilled water to make starch suspension in an aluminium pan, and distilled water was added to the pan until the starch concentration reached 40% (w/w, DW basis). The sample pan was sealed. The weighed sample was scanned at a rate of 5 °C/min over a temperature range of 25-110 °C, and an empty pan was taken as a control. Three gelatinization temperatures, including onset temperature (T_o), peak temperature (T_p) and ending temperature (T_e), were obtained from the thermal profiles. The analysis was performed in triplicate.

2.9 Experimental design

All experiments were carried in accordance with central composite design configuration. The ranges of CCD parameters are given in Table 1.

2.10 Statistical analysis

The experimental design and data analysis were performed using the Design-Expert software (ver. 8.0.6, Stat-Ease Inc., Minneapolis, USA). All experiments were conducted in in triplicates and presented as mean ± standard deviation (S.D.). Statistical significance of the data obtained was analyzed by one-way analysis of variance (ANOVA) whereas differences between the means were compared by Duncan's multiple-range test using SPSS version 18.0 at significance level of $p < 0.05$.

3 Results and discussion

3.1 RSM modelling for statistical optimization

This RSM-based process optimization offers several advantages, such as reduced operating cost of hands-on experiments by decreasing number of experimental runs, decrease in numerical noise with improved assessment of process variables in interactive manner and optimization of responses within region of interest in designed experiments. Results of target responses regarding pasting, texture and gelation parameters from experimental runs performed under CCD configuration, were shown in Tables 1-3 obtained as function of independent process variables (X_1: extraction time (min), X_2: extraction temperature (°C) and X_3: Potato Starch Conc. (%). The second order quadratic model equations of target responses were obtained in coded form after achieving fitting by multiple linear regression (MLR) analysis to obtain good fit and were shown in following subsections.

Analysis of variance (ANOVA) was employed to evaluate second order quadratic model equations with respect to their statistical significance (Table 2). Probability values (*p*-values) were employed as valid indicator to evaluate model significance, whereas, further evidence was achieved by analyzing goodness of fit (R^2 values) between model-predicted and experimental values of target responses. Each target response exhibited coefficient values which were utilized in formulation of final predictive equations, while insignificant terms were neglected. High model significance was indicative from the obtained lower probability values ($p < 0.0001$). The relatively higher R^2 values validated the statistical significance of formulated regression models. Model validity was also endorsed by the non-significant lack of fit value (> 0.05) and hence suggested better precision accompanied by higher degree of reliability. The fitted model for all target responses revealed significant effect of independent

Table 1. Independent variables and their levels.

Independent Variables	Symbol	Unit	-2	-1	0	1	2
Extraction time	X_1	Min	20	30	40	60	72
Extraction temperature	X_2	°C	55	65	75	85	95
Potato Starch Conc.	X3	%	10	15	20	25	30

Table 2. Central composite design configuration of target responses of pasting parameters.

Exp. No.	PT (°C)		PV (cP)		BV (cP)		FV (cP)		SV (cP)	
	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	70.11 ± 17	78	2495 ± 305	2502	876 ± 171	927	1687 ± 252	1751	595 ± 68	612
2	72.34 ± 13	75	2907 ± 401	3010	1478 ± 275	1562	1934 ± 250	2091	7098 ± 778	7086
3	76.34 ± 10	79	3178 ± 507	3193	1611 ± 165	1698	2141 ± 277	2242	8021 ± 812	8011
4	76.55 ± 17	77	3199 ± 612	3209	1698 ± 246	1781	2200 ± 288	2271	9854 ± 962	9876
5	69.54 ± 13	72	2276 ± 474	2378	9210 ± 240	9100	1509 ± 214	1591	678 ± 41	751
6	71.67 ± 19	75	2897 ± 515	2995	1775 ± 272	1763	2087 ± 297	2103	897 ± 68	902
7	74.11 ± 15	77	3067 ± 166	3162	1921 ± 187	2022	2398 ± 257	2451	923 ± 81	900
8	74.32 ± 13	73	3298 ± 523	3363	1932 ± 167	1998	2487 ± 262	2503	912 ± 65	1005
9	72.87 ± 11	76	2498 ± 580	2597	843 ± 278	921	2023 ± 246	2087	7897 ± 73	7902
10	76.78 ± 17	78	3364 ± 477	3398	1398 ± 191	1411	2411 ± 163	2509	8856 ± 77	8891
11	77.11 ± 12	79	3536 ± 601	3691	1498 ± 260	1421	2676 ± 224	2791	1023 ± 189	1035
12	76.94 ± 18	80	3643 ± 190	3773	1500 ± 283	1470	2687 ± 229	2783	9876 ± 69	9892
13	71.56 ± 14	76	2598 ± 226	2602	783 ± 151	799	1709 ± 173	1811	654 ± 87	692
14	76.24 ± 12	79	3187 ± 345	3190	1187 ± 221	1197	2167 ± 191	2193	726 ± 31	761
15	76.34 ± 11	80	3381 ± 241	3462	1265 ± 249	1291	2790 ± 171	2802	845 ± 73	876
16	76.59 ± 70	83	3396 ± 534	3469	1289 ± 291	1321	2812 ± 202	2863	891 ± 77	918

Table 3. Central composite design configuration of target responses of texture parameters.

Exp. No.	Hardness 1 (g)		Hardness 2 (g)		Springiness (mm)		Chewiness (mJ)	
	Actual	Predicted	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	39.24 ± 12	42	42.36 ± 15	44	13.78 ± 9	15	1.11 ± 1	1.14
2	34.45 ± 10	38	39.11 ± 7	42	13.99 ± 6	14	1.23 ± 2	1.35
3	33.11 ± 12	35	33.76 ± 11	35	14.59 ± 5	16	1.45 ± 4	1.52
4	31.23 ± 9	33	27.98 ± 15	29	14.94 ± 7	17	1.73 ± 3	1.71
5	37.34 ± 11	43	40.34 ± 10	44	14.34 ± 8	13	1.25 ± 1	1.35
6	35.38 ± 17	39	37.91 ± 12	40	14.98 ± 6	17	1.64 ± 2	1.69
7	32.11 ± 12	33	31.97 ± 13	33	15.21 ± 7	19	1.83 ± 1	1.89
8	29.58 ± 14	31	26.87 ± 14	27	15.34 ± 4	18	2.05 ± 1	2.11
9	40.26 ± 11	41	35.45 ± 17	38	13.98 ± 3	16	1.56 ± 2	1.59
10	37.76 ± 9	39	32.16 ± 15	35	14.14 ± 2	15	1.79 ± 1	1.84
11	35.42 ± 15	37	27.76 ± 11	29	15.96 ± 5	16	1.83 ± 1	1.89
12	31.23 ± 7	32	26.98 ± 18	31	15.67 ± 6	17	1.98 ± 2	2.02
13	41.22 ± 11	43	39.96 ± 16	42	14.23 ± 9	16	1.24 ± 1	1.31
14	36.87 ± 12	37	37.22 ± 11	39	14.97 ± 4	16	1.56 ± 2	1.61
15	32.23 ± 13	33	31.47 ± 10	34	14.93 ± 5	18	1.77 ± 2	1.81
16	30.78 ± 15	31	28.86 ± 12	30	15.06 ± 8	19	2.04 ± 1	2.16

process variables (X_1-X_3) on individual target responses related to pasting (Y_1 to Y_5), texture (Y_6 to Y_9) and gelation (Y_{10} to Y_{12}) properties. Higher degree of significance ($p < 0.0001$) was found from regression analysis equatorial model terms, such as main, cross-product (squared) and interaction effects. On basis of MLR equations, three-dimensional (3D) surface and contour plots were formed for elucidating interaction effects exhibited by independent process variables responsible for gel formulation. 3D plots are more useful usually in terms of their rising ridge or saddle forms to get profound understanding of main and cross-product effects on individual target responses (Ameer et al., 2017). In addition, the actual experimental values showed fair match with those of RSM model-predicted values (Tables 2-4).

Table 4. Central composite design configuration of target responses of gelation characteristics.

Exp. No.	To (°C)		Tp (°C)		Te (°C)	
	Actual	Predicted	Actual	Predicted	Actual	Predicted
1	104.11 ± 14	108	110.23 ± 11	118	100.78 ± 8	105
2	107.65 ± 10	109	114.87 ± 10	116	107.94 ± 15	109
3	109.26 ± 10	112	117.89 ± 17	122	119.87 ± 12	123
4	109.87 ± 14	113	118.76 ± 13	125	121.94 ± 13	127
5	102.98 ± 17	105	109.23 ± 15	112	102.96 ± 10	115
6	105.56 ± 16	108	113.56 ± 12	117	11.43 ± 12	17
7	108.89 ± 10	110	116.98 ± 14	119	115.84 ± 17	119
8	109.11 ± 15	111	119.42 ± 12	112	122.86 ± 10	129
9	103.56 ± 13	105	108.34 ± 10	110	104.21 ± 9	109
10	106.22 ± 18	109	113.87 ± 16	114	113.87 ± 11	116
11	108.43 ± 14	108	116.98 ± 16	119	121.67 ± 11	127
12	108.98 ± 17	110	117.95 ± 18	120	124.11 ± 13	129
13	105.34 ± 13	107	111.21 ± 13	115	107.24 ± 17	109
14	107.97 ± 16	109	114.87 ± 12	117	114.98 ± 11	116
15	109.21 ± 12	114	117.25 ± 18	121	119.54 ± 13	125
16	109.45 ± 15	116	119.78 ± 16	123	122.87 ± 18	129

3.2 Effects of independent variables on gel pasting properties

The results of pasting properties of potato starch gels obtained under CCD configuration are shown in Table 2. The pasting temperature (PT) of gels obtained from all experimental runs ranged from 69.54 to 77.11 °C. The average recorded PT from all runs of CCD configuration was found to be 74.35 °C. It was evident from the results that central point value of PT has shown most significant influence on gel formation from potato starch. The experimentally verified values of PT from run No. 5 and 11 were shown to be in fair agreement with those of mode-predicted values. The potato starch granules exhibit size in the range of 15-70 µm and consists of considerably large amount of amylopectin (about 79%) as compared to amylose content (21%). The starches with rich amylopectin content have been reported to exhibit substantially higher PV. Response surface and contour plots for pasting parameters; PT, PV, BV, FV and SV are given in Figure 1.

The peak viscosity (PV) of gels obtained from all experimental runs ranged from 2276 cP to 3643 cP. The average recorded PV from all runs of CCD configuration was found to be 3058 cP. It was evident from the results that PV exerted significant influence on gel formulation from potato starch. The experimentally verified values of PT from run No. 5 and 11 were shown to be in fair agreement with those of mode-predicted values. The highest PV (3643 cP) was observed in gel obtained from run No. 12 at following process variables; X_1: extraction time (46 min), X_2: extraction temperature (75 °C) and X_3: potato starch conc. (37%). Whereas, the lowest PV (2276 cP) was observed in gel obtained from run No. 5 at following process variables; X_1: extraction time (72 min), X_2: extraction temperature (95 °C) and X_3: potato starch conc. (30%).

The breakdown viscosity (BV) of gels obtained from all experimental runs ranged from 783 cP to 9210 cP. The average recorded BV from all runs of CCD configuration was found to be 1891 cP. It was evident from the results that BV exerted significant influence on gel formulation from potato starch. The experimentally verified values of BT from run No. 5 and 13 were shown to be in fair agreement with those of mode-predicted values. BV showed significant variations with corresponding rises in extraction time and temperature. BV represents possible susceptibility of starch granules breakdown after exposure to elevated heating temperatures and shearing (Kaur et al., 2007). The susceptibility of starch granules to shear disintegration shows increasing tendency in starches with low amylose content after swelling (Kaur et al., 2007). Similarly, final viscosity (FV) of gels obtained from all experimental runs ranged from 1509 cP to 2812 cP. The average recorded FV from all runs of CCD configuration was found to be 2232 cP. It was evident from the results that FV exerted significant ($p < 0.05$) influence on gel formulation from potato starch. The experimentally verified values of FV from run No. 5 and 16 were shown to be in fair agreement with those of mode-predicted values. FV showed significant variations with corresponding rises in extraction time and temperature. The gels showed setback viscosity (SV) from all experimental runs in the range of 595 cP to 9876 cP. The average recorded SV from all runs of CCD configuration was found to be 3734 cP. It was evident from the results that SV exerted significant ($p < 0.05$) influence on gel formulation from potato starch. The experimentally verified values of FV from run

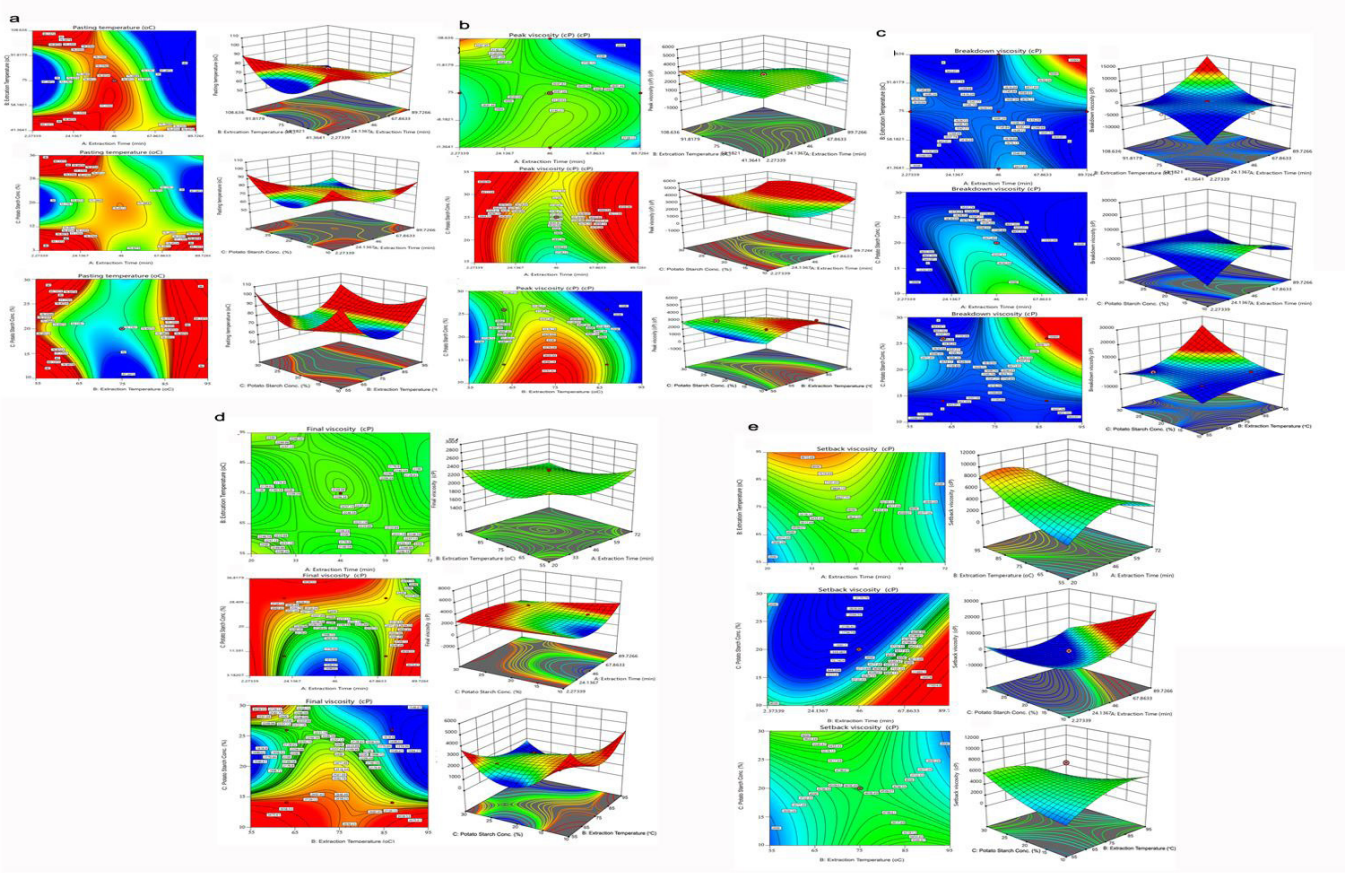

Figure 1. Response surface and contour plots for pasting parameters; PT (a), PV (b), BV (c), FV (d) and SV (e).

No. 1 and 12 were shown to be in fair agreement with those of mode-predicted values. FV showed significant variations with corresponding rises in extraction time, temperature and potato starch concentration. These findings are in line with the previously reported results of Li et al. (2014) who also concluded that amylopectin-rich starches exhibited higher PV, BV, FV and SV values. Generally, the increases in sugar and starch concentrations are positively correlated to increased gelatinization temperatures and lead to enhanced degree of retrogradation (Sun et al., 2014).

3.3 Effects of independent variables on gel texture properties

The results of textural properties of potato starch gels determined by texture profile analysis obtained under CCD configuration are shown in Table 3. It was evident from the 3D response surface and contour plots that independent variables, such as extraction time, extraction temperature and potato starch concentration significantly affected ($p < 0.05$) texture. It was observed from the RSM analysis that target responses regarding texture characteristics (hardness 1, hardness 2, springiness and chewiness) were significantly reliant on potato starch conc. followed by extraction time and temperature. ($p < 0.05$). Hardness 1 and hardness 2 values of gels obtained from all experimental runs ranged 28.58-41.23 and 26.87-42.36 units, respectively. The average recorded values for both hardness parameters was found to be quite similar (34.24) in magnitude. It was evident from the results that central point value of hardness that independent process parameters did not exhibit any significant influence and hardness showed stability invariably. Generally, the increases in hardness was observed with corresponding rises in extraction time and potato starch concentration. Response surface and contour plots for textural parameters; hardness 1, hardness 2, springiness, and chewiness are given in Figure 2.

The springiness is also denoted with another term of elasticity which is an indicative of gel's capacity to spring back well after deformation during first applied compression (Gökşen & Ekiz, 2019). The springiness values of potato starch gel from all experimental runs of CCD configuration was found in range of 13.78 to 15.96. At lower concentrations of potato starch, the gel exhibited lower springiness values whereas increases in potato starch caused corresponding rises in gel springiness gradually. Lower springiness value indicated loss of elasticity of gel. The experimental springiness, hardness and chewiness values were shown to be in fair agreement with those of mode-predicted values. These results are in correspondence with findings of Teng et al. (2013) who reported increases in springiness values with corresponding rises in sugar and starch concentrations.

The linear, cross-product and quadratic effects of model were fund to be statistically significant

3.4 Effects of independent variables on gelation characteristics

Thermal stability was monitored by evaluating key thermal parameters like Onset temperature; To (°C), peak temperature;

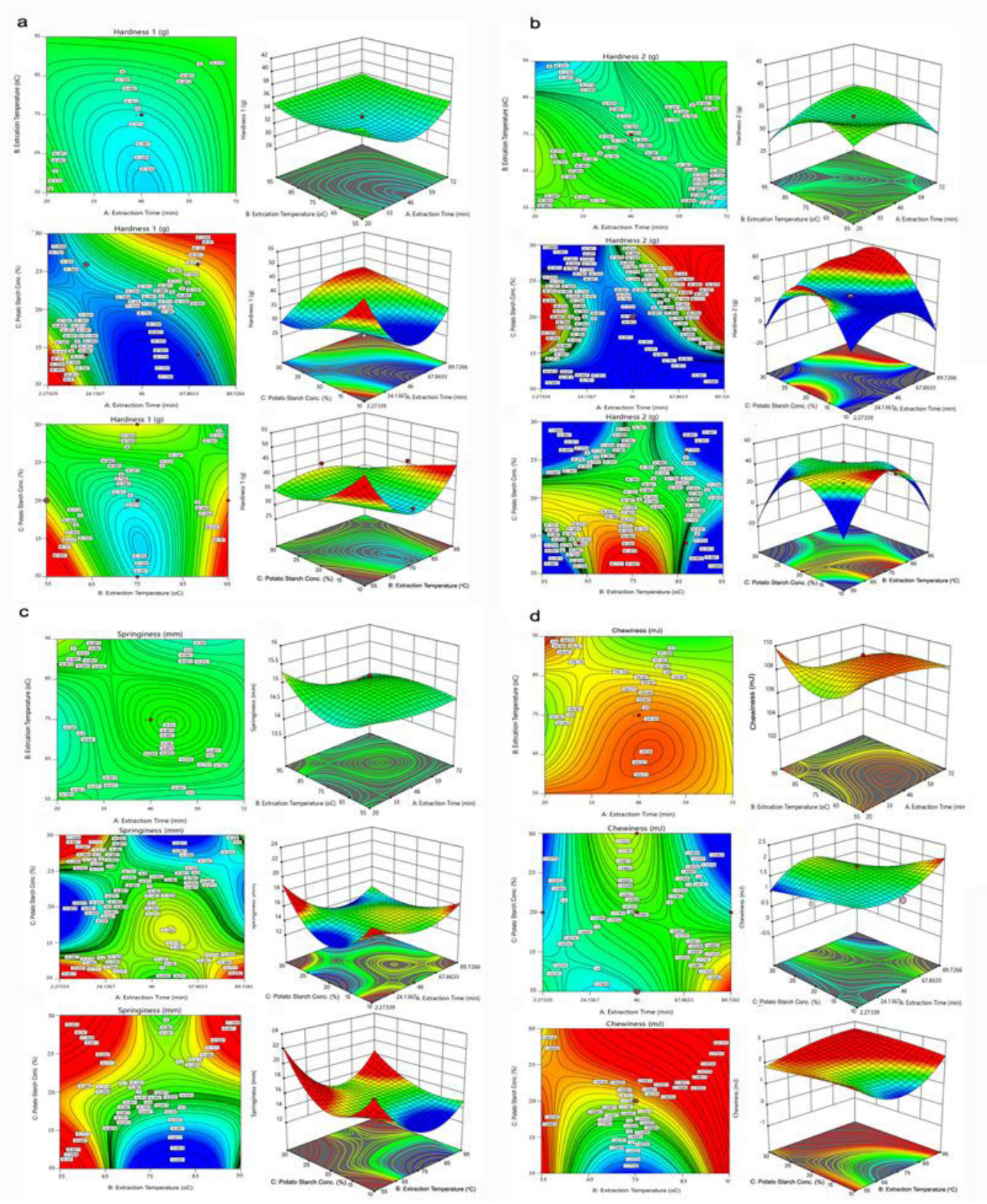

Figure 2. Response surface and contour plots for textural parameters; hardness 1 (a), hardness 2 (b), springiness (c), chewiness (d).

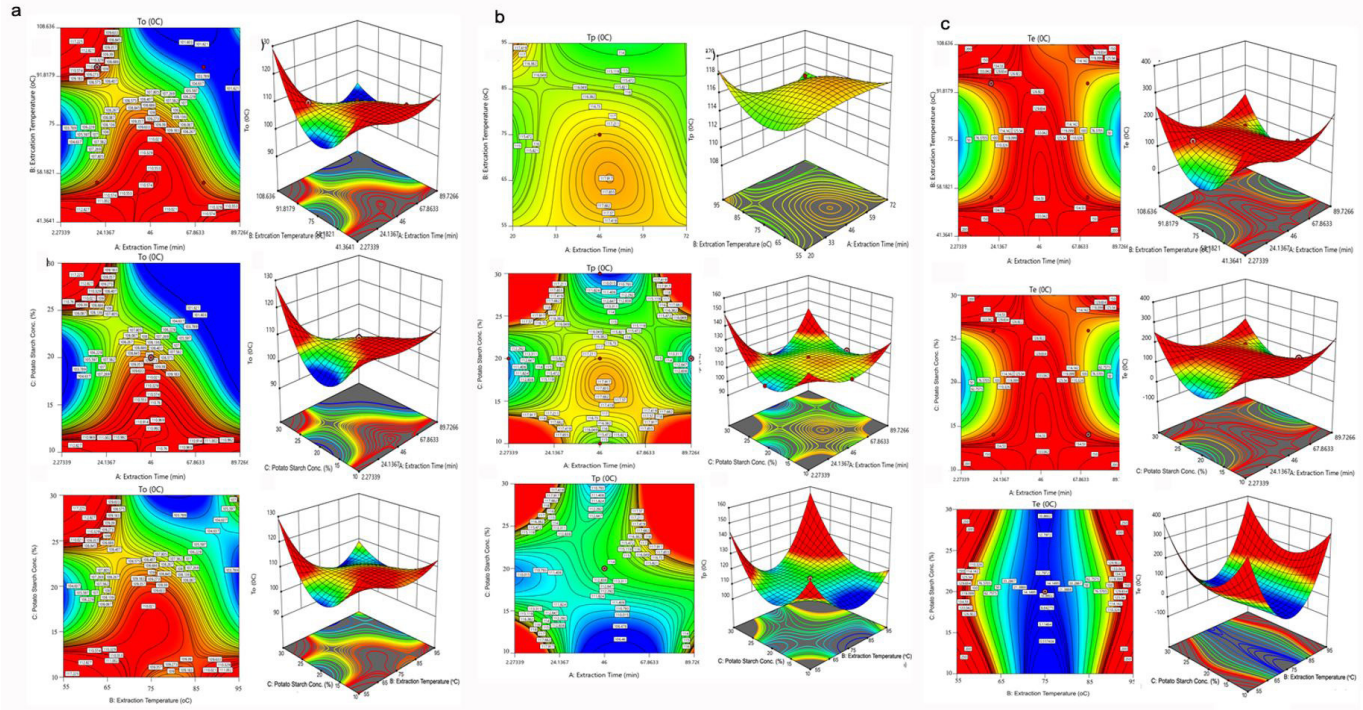

Figure 3. Response surface and contour plots for gelation parameters; To (°C) (a), Tp (°C) (b) and Te (°C) (c).

Tp (°C), and end temperature; Te (°C). The results regarding gelation characteristics of potato starch gels determined obtained under CCD configuration are shown in Table 4. T_o showed range from 102.98 to 109.87 °C whereas, the mean T_o was maintained at 107.20 °C. It was evident from the results of this study that T_o showed relatively consistent tendency during majority of experimental runs while a maxima (109.87 °C) and minima (102.98 °C) were observed from experimental runs No. 4 and 5, respectively. The T_o value gives the indication about degree of disintegration in internal starch granules and this disintegration led to polysaccharides release in surrounding medium. Response surface and contour plots for gelation parameters; To (°C), Tp (°C) and Te (°C) are given in Figure 3.

Similarly, T_p was ranged as 108.34-119.78 °C whereas, the mean T_p was maintained at 114.97 °C. It was evident from the results of this study that T_p showed relatively slight modification during majority of experimental runs while, maxima (119.78 °C) and minima (108.34 °C) were observed from experimental runs No. 16 and 9, respectively. Generally, a high Tp is an indicative of high degree of crystallinity in starch granules (Souza et al., 2001).

T_e showed range from 100.78 to 124.11 °C whereas, the mean T_e was maintained at 114.28 °C. It was evident from the results of this study that T_e showed relatively consistent tendency during majority of experimental runs while maxima (124.11 °C) and minima (100.78 °C) were observed from experimental runs No. 17 and 1, respectively. These results in accordance with findings of Li et al. (2014).

4 Conclusion

The pasting temperature (PT) of gels obtained from all experimental runs ranged from 69.54 to 77.11 °C. The average recorded PT from all runs of CCD configuration was found to be 74.35 °C. It was evident from the results that central point value of PT has shown most significant influence on gel formation from potato starch. The breakdown viscosity (BV) of gels obtained from all experimental runs ranged from 783 cP to 9210 cP. The average recorded BV from all runs of CCD configuration was found to be 1891 cP. It was evident from the results that BV exerted significant influence on gel formulation from potato starch. Similarly, final viscosity (FV) of gels obtained from all experimental runs ranged from 1509 cP to 2812 cP. The average recorded FV from all runs of CCD configuration was found to be 2232 cP. FV showed significant variations with corresponding rises in extraction time and temperature.

The gels showed setback viscosity (SV) from all experimental runs in the range of 595 cP to 9876 cP. The average recorded SV from all runs of CCD configuration was found to be 3734 cP. It was evident from the 3D response surface and contour plots that independent variables, such as extraction time, extraction temperature and potato starch concentration significantly affected ($p < 0.05$) texture. It was observed from the RSM analysis that target responses regarding texture characteristics (hardness 1, hardness 2, springiness and chewiness) were significantly reliant on potato starch conc. followed by extraction time and temperature. T_o showed range from 102.98 to 109.87 °C whereas, the mean T_o was maintained at 107.20 °C. It was evident from the results of this study that T_o showed relatively consistent tendency during majority of experimental runs while a maxima (109.87 °C) and minima (102.98 °C) were observed from experimental runs No. 4 and 5, respectively. The T_o value gives the indication about degree of disintegration in internal starch granules and this disintegration led to polysaccharides release in surrounding medium.

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