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Research Article

Effect of processing parameters on texture and yield of tofu

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Abstract

The effect of coagulation temperature and pressing pressure on yield and texture of tofu were studied. Three different pressures were tested (1.0, 1.5, and 2.0 Kg/cm^2) for moisture and protein content of tofu with four coagulation temperatures (80, 85, 90 and 95°C). No significant difference was observed among treatments in moisture content, but protein content was significantly higher with higher pressure. Firmness, elasticity, chewiness, adhesiveness and cohesiveness were evaluated. There was an increasing trend in textural properties with increase in coagulation temperature from 80˚C to 90˚C but a slight decline of most of these textural properties was observed as the temperature increased from 90 to 95˚C, except for elasticity and adhesiveness. Chewiness was highly correlated with firmness (0.94) and elasticity (0.91). Firmness was highly correlated with coagulation temperature (0.77). All textural properties tested were highly dependent on coagulation temperature (R^2 = 0.98 to 0.99), except cohesiveness (0.75).

This study will help tofu manufacturers in India and other Asian countries to control their overall quality and yield. Tofu is the richest source of protein for vegetarian people in India. Increasing yield of tofu and providing a better texture will make it available for more and more people with increasing preference.

Keywords: Tofu, texture, yield, firmness, elasticity, India

Introduction

Soybean or soymilk has always been a rich source of protein which is inexpensive [1], and abundantly available. Soymilk is used in various food products such as tofu, fruit flavoured puddings, calcium and protein rich soymilk. Tofu is one of the most popular soy-products and is prepared by coagulating soymilk. The quality of tofu depends on several parameters such as coagulation method, processing condition, texture, the content of two storage protein components glycinin and β-conglycinin and their ratio [2], concentration and type of the coagulant used [3, 4], and temperature of coagulation. Tofu has been reported as low-calorie food and rich source of iron, calcium, low in saturated fat and as a source of isoflavones which can mimic human estrogens and can have beneficial effects on human health [5].

To improve the texture and increase the yield of tofu, researchers has been engaged to find better coagulation methods, concentration of coagulants and optimum temperature of coagulation. Hou and others [3] studied the effect of two different coagulants (calcium sulphate and modified nigari (Japanese name for magnesium chloride), three stirring speeds (137, 207 and 285 rpm), and six stirring times (5, 10, 15, 20, 25 and 30 sec) on yield and textural properties of soft tofu. This group found that tofu made by the highest stirring speed (285 rpm) had a lower yield, but higher brittleness force, hardness and elasticity than tofu made at 207 rpm. Other factors that affected yield of tofu were whole soybean (higher yield) versus soybean flakes [6], heating method where steam injected cooker system had higher yield as compared to steam jacketed kettle system [7]. Similarly, texture of tofu is dependent on several factors**.** Schaefer and Love [8] reported that calcium level was significantly correlated with tofu hardness (r = 0.73) and springiness (r = 0.83). Tofu protein was significantly related to fracturability (r = 0.75). They also mentioned that the higher the protein varieties, higher would be protein content (Vinton/Vinton 81) resulting in tofu that was firmer with springier texture than that of tofu made from Amsoy 71 beans. Concentration of calcium sulphate also affects the overall yield and texture of tofu [4]. These researchers observed a negative correlation between $CaSO_4$ and both yield and protein recovery for all varieties of soybean. There is no published data for the effect of coagulation temperature on tofu yield and texture but it has been reported by Hui [9] that soymilk temperature when coagulants are added affects the coagulation rate and quality of tofu. Hui [9] also mentioned that yield and moisture content decreased as the temperature of coagulation increased because high temperature will lead to fast coagulation and less water binding capacity of protein.

The objective of this study was to evaluate the effect of four different coagulation temperatures ranging from 80˚C to 95˚C on firmness, elasticity, chewiness, adhesiveness, cohesiveness and yield of tofu. Moisture and protein content of the final tofu were also evaluated as affected by three different pressing pressures (1.0, 1.5, and 2.0 Kg/cm^2).

Materials and Methods

Tofu making

Tofu was prepared at the College of Dairy Science and Technology facility (Maharana Pratap University, Udaipur, India). The soybean flakes (Assign India Corporation, Hospet, India) were soaked in water (1:3 w/v) overnight at room temperature. The soak water was removed and flakes were washed with fresh water, then ground with fresh water (1:10 w/v). The semi-condensed mixture was then filtered with muslin (cheese) cloth with fine mesh to obtain a milky liquid (soymilk). Four batches of soymilk (5 litres each) were then heated to 80˚C, 85˚C, 90˚C and 95˚C. For coagulation of soymilk, food grade 0.5% calcium sulphate (Sujata Chemicals, Baroda, Gujarat) solution was added with constant stirring. Stirring was stopped after complete coagulation (5-7 minutes) and content was kept undisturbed for 15 min at room temperature. The coagulum was collected with the help of fine muslin cloth and transferred to a wooden mold lined with plastic sheet and divided into three equal parts for pressing. Pressure applied (by putting weights) on tofu was 1.0, 1.5 and 2.0 kg/cm^2 for 45 min. The pressed tofu was then removed from the mold and dipped in chilled water for 30 min. The tofu was then placed on clean muslin cloth to remove free water [10]. The weight of freshly formed tofu was recorded. Tofu yield was expressed as kg tofu per kg of soybeans on dry basis [4].

Textural analysis

The texture profile analysis (TPA) of tofu was evaluated for its firmness (hardness), elasticity (springiness), chewiness, adhesiveness and cohesiveness using a texture analyzer (TA.XT *plus*, Stable Micro Systems, London, UK) equipped with 5 kg load cell. The analyzer was linked to a computer that recorded the data via a software program XT.RA (Texture Technologies Corp., Scardale, NY) [11, 12]. A 5 mm cylindrical probe was used to cut samples. The crosshead speed was set at 1 mm s^{-1} and the probe travelled 75% of the depth into tofu sample in the first stage.

Moisture and protein contents

Moisture content of tofu was determined by the AACC method 44-31 [13] and protein content was determined by micro Kjeldahl method [14]. Nitrogen to protein conversion factor of 6.25 was used.

Statistical analysis

All treatments were evaluated in triplicate. Data were evaluated using the PROC ANOVA method of SAS 9.1.3 (SAS Institute, Inc., NC). Analysis of variance (ANOVA) was conducted, and differences between group means were analyzed by the LSD. Student t-test was used for establishing the effect of temperature and pressure on moisture content of tofu. Statistical significance was established at $p < 0.05$. Regression analysis with binomial function (order = 2) was used to determine apparent dependence among measurements. Correlation coefficients were calculated using Pearson's technique for all parameters involved [15].

Results and Discussion

Moisture and protein content

The moisture and protein content of tofu coagulated at four different temperatures and pressed at three different pressures were evaluated. There was no significant effect of temperature and pressure and their interaction on tofu final moisture content (Table 1).

Table 1. **ANOVA procedure for the effect of temperature and pressure on moisture content of tofu (N = 36).**

Source	DF	ANOVA SS	Mean Square	F value	p-value*
Temperature	3	141.11	47.04	0.08	0.97
Pressure	2	1466.38	733.19	1.25	0.32
Rep	2	209.61	104.81	0.18	0.84
Temperature*pressure	6	1719.20	286.53	0.49	0.81
Temperature*rep	6	3224.40	537.40	0.91	0.52
Pressure*rep	4	403.60	100.90	0.17	0.95

*Level of significance p<0.05

Tofu protein content was significantly increased as the pressing pressure increased from 1.0 to 2.0 Kg/cm^2 but protein content was not affected by coagulation temperature (Table 2). The intermediate pressure application of 1.5 kg/cm^2 was not significantly different (Table 2) from other two pressure applications and hence was chosen for further study of tofu texture and yield. The slight change in moisture was reported to cause drastic change in protein content of tofu. Further research is needed to explain this phenomenon.

Table 2. **Effect of temperature and pressure on protein content (%) of tofu.**

Temperature (°C)	Pressure (kg/cm^2)	N	Mean±SD
80	1.0	9	7.65^a±2.76
80	1.5	9	13.19^{ab}±2.00
80	2.0	9	17.19^b±2.28
85	1.0	9	10.63^a±3.05
85	1.5	9	13.65^{ab}±2.01
85	2.0	9	16.83^b±2.53
90	1.0	9	13.95^a±1.49
90	1.5	9	13.62^{ab}±0.55
90	2.0	9	16.36^b±0.36
95	1.0	9	20.44^a±0.70
95	1.5	9	10.92^{ab}±1.99
95	2.0	9	16.29^b±1.52

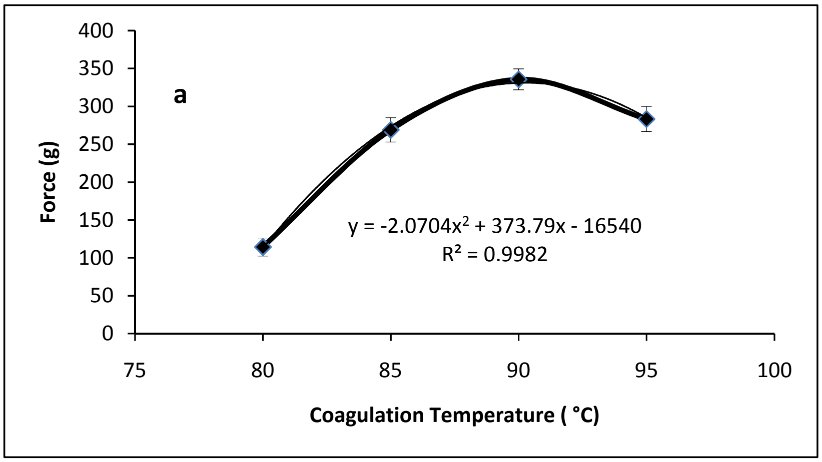
$^{a, b}$ Superscripts with different letters within column are different (p <0.05)

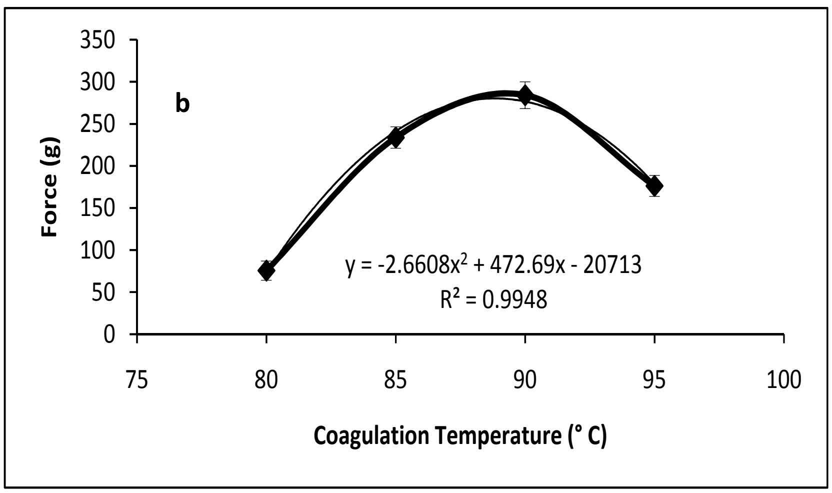
Texture quality and yield

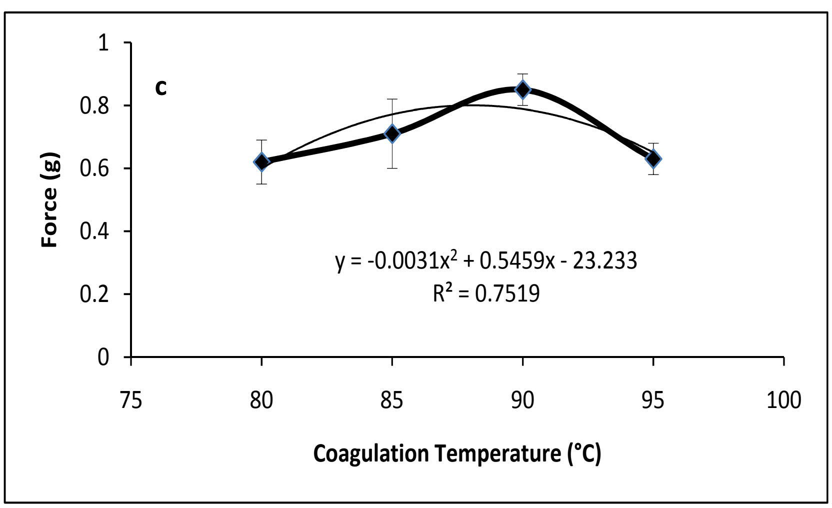
The texture of tofu pressed at 1.5 kg/cm^2 was evaluated on TA.XT *plus* Texture Analyzer and data are presented in Figure 1 against coagulation temperature. The intermediate pressing pressure 1.5 kg/cm^2 was chosen based on its intermediary effect on moisture and protein content of tofu in experiment 1. Tofu firmness, chewiness and cohesiveness showed a similar pattern of increase in values as coagulation temperature increased from 80 to 90˚C, but followed by a slight decrease as temperature increased from 90 to 95˚C (Fig 1a, 1b and 1c). Elasticity (springiness) was observed to increase slightly from 80 to 85˚C and then decreased (Fig. 1d). The adhesiveness data was observed to decrease from 80 to 90˚C and then trended slightly upwards (Fig. 1e). The microstructure of tofu is responsible for texture and depends on tofu composition and manufacturing processes. Thus the change in temperature of coagulation affects protein functionality [9]. The firmness of tofu increased from 114.33 to 335.67 (peak penetration force (g) as temperature increased from 80 to 90˚C, but then decreased with further increase in coagulation temperature. The regression coefficient of firmness was high ($r = 0.99$) with coagulation temperature (Fig. 1a) indicating that there is a definite effect of coagulation temperature on tofu firmness. This is in general agreement with the results obtained by Saio [16]. The optimum coagulation should be selected based on the desired firmness of the product. The cohesiveness and elasticity showed a similar pattern where increased coagulation temperature was associated with increased cohesiveness, though elasticity did not show any significant difference (Fig. 1c and 1d). These two parameters are closely related since both measure product deformation and both depend on the strength of the protein matrix, heat treatment, protein interaction, flexibility and degree of unfolding of protein [17].

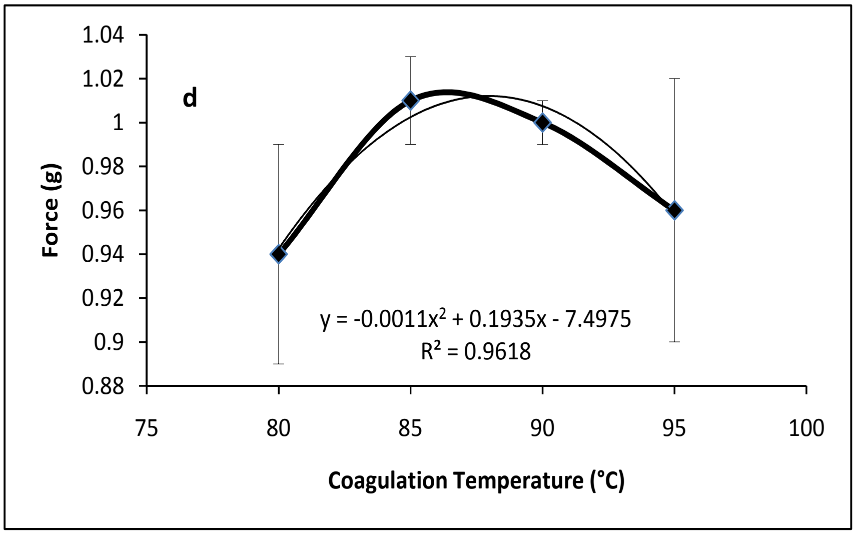
It can be observed that tofu adhesiveness increased as the coagulation temperature increased from 80-90˚C in Figure 1(e). But further decrease in the coagulation temperature to 95˚C, increased the adhesiveness. This pattern can be explained by the nature of the protein matrix that may contribute to adhesive tendency of tofu as to adhere to the mouth. The chewiness showed highly significant differences among all coagulation temperature treatments. Adhesiveness was only significantly different between 80°C and 90°C. The values at 80˚C and 85˚C are significantly different from each other but the values at 85˚C and 90˚C are not different. Similarly the values of adhesiveness at 90˚C and 95˚C are not different ($p < 0.05$).

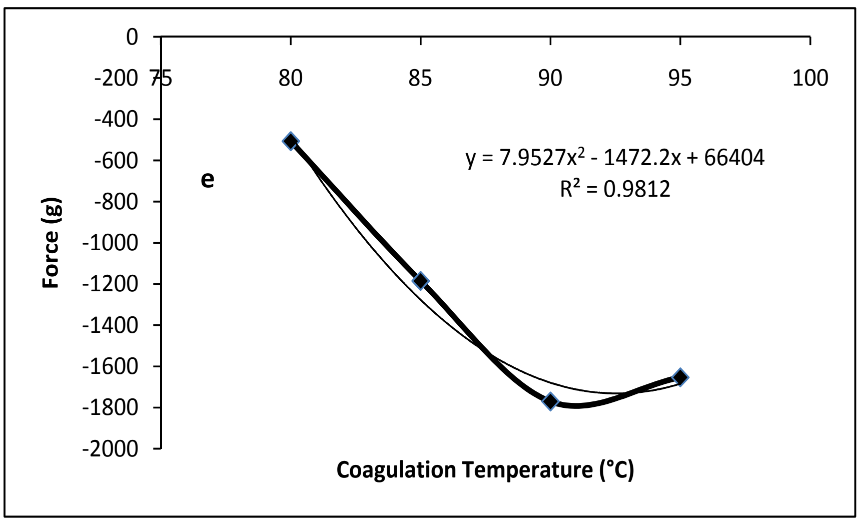
The yield of tofu was calculated as kilograms of tofu per kilogram of dry soybean flakes. The results are represented in Figure 1(f). As depicted in the figure, there is an increase in yield of tofu as the coagulation temperature increases. The yield increased from 1.35±0.08 to 1.99±0.02 as coagulation temperature increased from 80 to 90˚C. However, there was a decline in yield from 1.99±0.02 to 1.26±0.12 with further increase in temperature. This could be due to the reason that high activation energy was obtained by protein matrix at high temperature causing low water binding capacity [9]. The optimum temperature of coagulation to obtain higher yield is 90˚C. The lower yield at lower temperature was also due to poor water binding capacity of protein as tofu coagulation temperature increased from 80 to 90°C, yield increases but at 95°C coagulation temperature, yield decreases, probably due to decreased protein water holding capacity at this temperature [9].


a
Force (g)
Coagulation Temperature (°C)
y = -2.0704x² + 373.79x - 16540
R² = 0.9982


b
Force (g)
Coagulation Temperature (° C)
y = -2.6608x² + 472.69x - 20713
R² = 0.9948


c
Force (g)
Coagulation Temperature (°C)
y = -0.0031x² + 0.5459x - 23.233
R² = 0.7519


d
Force (g)
1.04
1.02
1
0.98
0.96
0.94
0.92
0.9
0.88
y = -0.0011x² + 0.1935x - 7.4975
R² = 0.9618
75
80
85
90
95
100
Coagulation Temperature (°C)


e
Force (g)
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
-1800
-2000
75
80
85
90
95
100
y = 7.9527x² - 1472.2x + 66404
R² = 0.9812
Coagulation Temperature (°C)

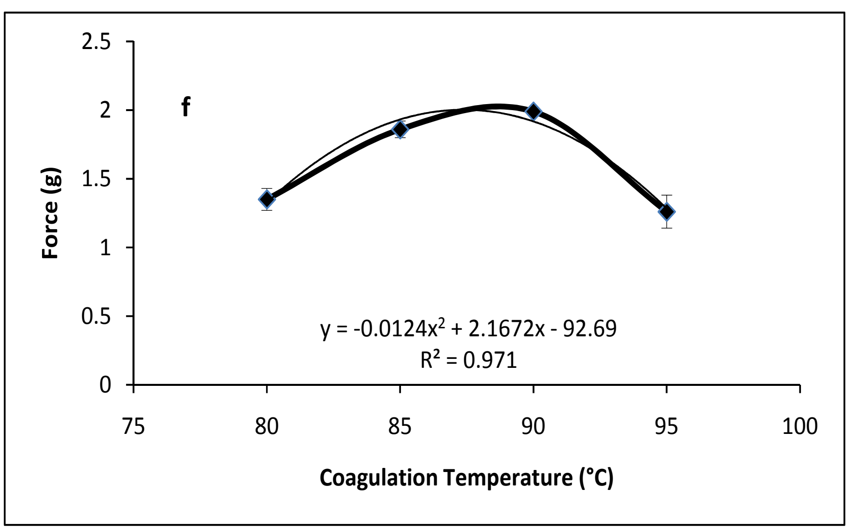

f
Force (g)
2.5
2
1.5
1
0.5
0
y = -0.0124x² + 2.1672x - 92.69
R² = 0.971
75
80
85
90
95
100
Coagulation Temperature (°C)

Figure 1. Effect of coagulation temperature on (a) firmness (b) chewiness (c) cohesiveness (d) elasticity (e) adhesiveness and (f) yield of tofu.

The correlation coefficients shown in Table 3 clearly depict the relationship between tofu properties and treatments. For instance, temperature showed the highest correlation with firmness (0.77) and least with adhesiveness (-0.91). Similarly chewiness had highest correlation with firmness (0.94), followed by elasticity (0.91), indicating that as chewiness increased, firmness and elasticity also increased. Yield of tofu had a low correlation coefficient with coagulation temperature (0.97). This again confirms that coagulation temperature affects the yield. Based on these results, the optimum tofu coagulation temperature was 90˚C which also increased the overall quality as well as yield. Further study would be to correlate sensory evaluation of tofu against the instrumental analysis, coagulated at different temperatures and confirm the optimum processing parameters of tofu for consumer preference.

Table 3. **Pearson's correlation coefficient for textural properties and yield of tofu.**

	Temp.	Firmness	Chewiness	Cohesiveness	Elasticity	Adhesiveness	Yield
Temperature	1.00	0.77	0.51	0.21	0.20	-0.91	0.97
Firmness		1.00	0.94	0.71	0.75	-0.96	0.59
Chewiness			1.00	0.86	0.91	-0.81	0.83
Cohesiveness				1.00	0.75	-0.59	0.90
Elasticity					1.00	-0.53	0.90
Adhesiveness						1.00	-0.37
Yield							1.00

Conclusions

Tofu is a rich and major source of protein for the population in general and vegetarians in particular. Therefore, improving tofu's textural properties and yield is an important area for food research. To the best knowledge of the authors, this study is the first study to measure changes in tofu quality as affected by coagulation temperature. The texture and yield of tofu can be increased by increasing the coagulation temperature from 80 to 90°C. This study suggests that the optimum coagulation temperature for tofu is 90˚C. The increase in yield of tofu is very important for both industry and households, to make it available to as many people as possible.

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