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Extrusion of tarhana: effect of operating variables on starch gelatinization

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Tarhana, a traditional Turkish cereal food, was extruded using a twin-screw extruder. The effect of barrel temperature (60–120 °C), feed rate (10–20 kg h^{-1}, wet basis) and screw speed (100–300 rpm) on starch gelatinization was investigated using response surface methodology at constant moisture content (43%, wet basis). A regression equation for predicting starch gelatinization was developed. Barrel temperature had the most pronounced effect on starch gelatinization at constant moisture content, followed by feed rate and screw speed. Response surface plots suggest that a high degree of starch gelatinization can be achieved when tarhana is extruded at high barrel temperatures and screw speeds but low feed rates (i.e. high residence times). Copyright © 1996 Elsevier Science Ltd

INTRODUCTION

Fermented milk–cereal mixtures play an important role in the diets of many people in the Middle East. Tarhana, a popular traditional yogurt–wheat flour mixture used in soup making, is widely consumed in Turkey and forms a significant part of the diet, especially of young children and the elderly (Siyamoglu, 1961). It is prepared by mixing yogurt, wheat flour, yeast and a variety of cooked vegetables and spices followed by fermentation for 1–7 days (Campbell-Platt, 1987). After fermentation the mixture is sun dried. Tarhana has an acidic and sour taste with a strong yeasty flavour.

Food products are instantized and agglomerated using a variety of processes including spray, freeze- and roller-drying (Schubert, 1993). Extrusion cooking is an extremely versatile process for producing cereal-based instant foods (Cheftel, 1986). The traditional batch method of tarhana manufacture is not automated, with manufacturing capacities being low and highly labour intensive. Developing tarhana using extrusion cooking would allow tarhana to be produced at a lower cost due to more efficient use of energy and greater process control, with greater production capacities (Harper, 1979). Moreover, instant tarhana powder would be very valuable in hospital and school canteens facilitating its usage, as well as in the home–householding.

Starch gelatinization is reported as an essential factor providing instant properties of starch-based products (Schubert, 1993). The purpose of this study was to develop a method for extrusion cooking of tarhana and to evaluate the effects of barrel temperature, screw speed and feed rate on the gelatinization of starch in extruded tarhana using response surface methodology.

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MATERIALS AND METHODS

Materials

The ingredients used in tarhana preparation were purchased from local markets in Manchester. The crude protein content of the wheat flour used was 12.4%. Yogurt was made from cow's milk and had a fat content of 3.6%. Tomato puree was double concentrated. Yeast was baker's yeast in active dry form. The spices used were in powder form. Food grade lactic acid solution was used in the experiments (86%, w/w).

Experimental design

A full factorial three-variable, three-level experimental design with six replications at centre point (Gacula & Singh, 1984) was used, with barrel temperature, screw speed and feed rate being the process variables (Table 1). This generated 33 extrusion runs. A range of operating variables was found to be the best choice for feasible tarhana extrusion.

Extrusion

Extrusion of tarhana was performed in a co-rotating twin-screw extruder (Continua 37, Werner and Pfleiderer,

Table 1. Extrusion variables and experimental design levels used

Variables	Code	−1	0	+1
Barrel temperature (°C)	X_1	60	90	120
Feed rate (kg h^{-1}, wet basis)	X_2	10	15	20
Screw speed (rpm)	X_3	100	200	300

Stuttgart, Germany). The diameter of screws and screw length:screw diameter ratio were 37 mm and $l/d=27$, respectively. The screws were made up of self-wiping elements except for a section consisting of short reverse and forwarding elements (Fig. 1). The barrel was heated using circulating oil from an independent heating unit with the feed zone being cooled by tap water. Two circular dies each of 4 mm diameter, 19 mm length were used. One temperature and one pressure probe were inserted in the barrel just before the die.

Onions were peeled, cut into halves and placed into a bowl chopper (Kilia Type 201, Kiel, Germany) together with the rest of the ingredients, other than the wheat flour (Table 2), to obtain a slurry which could be fed to the extruder using a Watson Marlow (Falmouth, UK) peristaltic pump. The wheat flour was fed into the extruder using a volumetric twin-screw metering screw feeder (Rospen, Gloucester, UK). The overall moisture content and pH of tarhana (wheat flour plus the slurry) were 43% (wet basis) and 4.2, respectively.

When the extrusion system reached a steady state (usually less than 20 min) as indicated by constant percentage torque, pressure and constant material temperature samples were taken. All samples collected were oven-dried for 24 h at 55°C before grinding in a laboratory mill (Retsch GmbH, Haan, Germany) to a particle size range of 250–212 μm. Ground extrudates were stored in air-tight glass containers and held at room temperature until analysis.

Determination of starch gelatinization

The extent of starch gelatinization in extruded tarhana samples was determined by a modified method of Wootton & Chaudhry (1980), which is based on the formation of a blue iodine complex by amylose released

Table 2. Composition of extruded tarhana

Ingredient	Percent of total weight (wet basis)
White wheat flour	50.0
Yogurt	25.0
Onions	12.0
Tomato puree	6.0
Salt	4.0
Yeast	1.0
Paprika	1.0
Lactic acid solution	0.6
Dill	0.2
Mint	0.2

during gelatinization, as follows: A 2.0 g sample (dry basis) was mixed with distilled water (100 ml) in a laboratory blender (Stomacher 400) for 2 min at room temperature. The suspension was centrifuged at 1500 ***g*** for 10 min at room temperature and 1 ml iodine solution (4% KI, 1% I_2) was added to 1 ml of the supernatant and made up to 10 ml with distilled water. The absorbance of the resulting solution was read at 600 nm using a spectrophotometer which was calibrated against a reference solution containing all reagents except the tarhana sample (A1). In a separate analysis freeze-dried unextruded tarhana powder was heated and brought to boiling in water (5% w/w) with gentle stirring, held for 5 min boiling followed by freeze-drying. The sample was then ground to the same particle size as the extruded samples. This powder was subjected to the same procedure as above to measure the intensity of the blue colour formed spectrophotometrically (A2). Percent starch gelatinization in extruded samples was calculated using the relationship (A1/A2)×100 which meant the starch in boiled tarhana sample was accepted as 100% gelatinized (Sopade & Le Grys, 1991).

Statistical analysis

Response surface methodology was applied to the starch gelatinization data using a commercial statistical package, Design-Expert version 4.0 (Stat-Ease, Inc., Minneapolis, USA). A second order polynomial was fitted to the data to obtain a regression equation showing the importance of each operational variable and

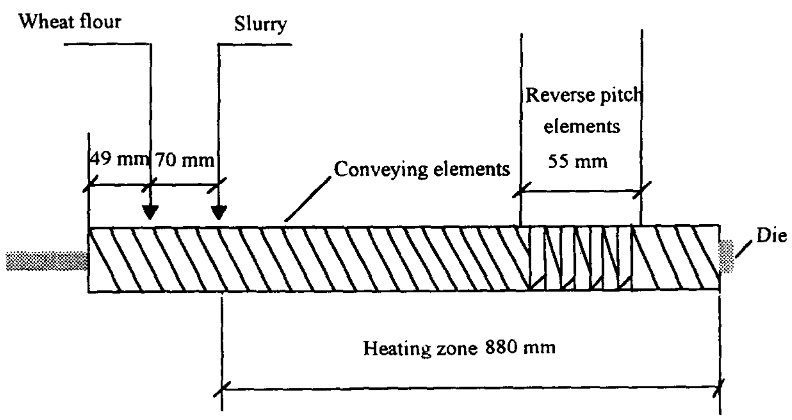

Fig. 1. The extruder screw configuration and the location of barrel heating zone and feed ports.

their interactions on starch gelatinization. Statistical significance of the terms in the regression equation were examined. Response surface plots were generated with the same software.

RESULTS AND DISCUSSION

Previous studies on tarhana showed that the nutritional value did not change considerably during fermentation (Ibanoglu *et al.*, 1995*a*). The tarhana fermentation is a fermentation by lactic acid bacteria, hence characterized by the production of lactic acid (Ibanoglu *et al.*, 1995*b*). Therefore, the fermentation stage was omitted in extruded tarhana production and the typical pH level was achieved by the addition of lactic acid prior to extrusion.

The analytical procedure used in this study to estimate the extent of starch gelatinization in extruded tarhana powders was based on the amount of amylose solubilized during extrusion. This gives a deep blue colour with iodine so that the intensity of the aqueous amylose–iodine complex can be measured spectrophotometrically. In the conventional gelatinization model (i.e. excess water and shearless medium) heating disrupts internal hydrogen bondings which hold starch granules together, leading to the swelling of the granules and subsequent release of starch molecules, mostly amylose (Blanshard, 1979). However, this model is not valid in extrusion processes due to the low moisture content of the materials being extruded and the presence of high shear occurring in the extruder barrel, which could promote starch dextrinization (Gomez & Aguilera, 1984). Since the moisture content of tarhana was high during extrusion (43%, wet basis), it was believed that the gelatinization mechanism occurring during tarhana extrusion would be similar to that occurring in the conventional boiling process. Therefore, it is possible that measurement of the amylose solubilized by the method applied in this study gives reliable results for the extent of starch gelatinization in extruded tarhana.

Table 3. Regression equation coefficients for percent starch gelatinization in extruded tarhana

Independent variables [a]	Coefficients	R^2 (adjusted)
Constant	16.2	0.90
X_1	21.8**	
X_2	−10.7**	
X_3	5.8**	
X_1^2	22.2**	
X_2^2	4.7	
X_3^2	0.6	
X_1X_2	−9.4**	
X_1X_3	5.9*	
X_2X_3	0.4	

[a] X_1, barrel temperature at heating zone of the extruder (°C); X_2, feed rate of tarhana (kg h^{-1}, wet basis); X_3, screw speed (rpm).
* Significant at $p < 0.05$.
** Significant at $p < 0.01$.

The coefficients in the regression equation can be used to examine the significance of each term relative to each other (Khuri & Cornell, 1987). It was observed that, at constant moisture content, barrel temperature is the

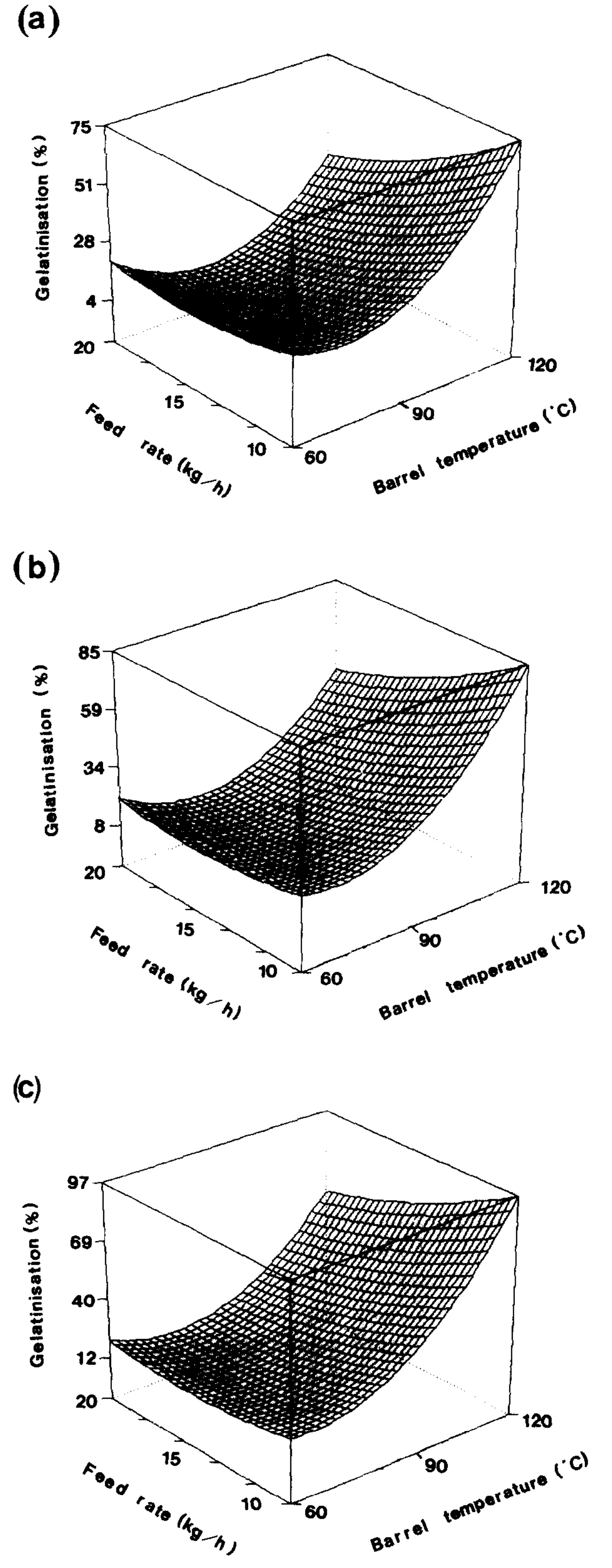

Fig. 2. Effect of barrel temperature and feed rate on starch gelatinization of extruded tarhana at (a) 100 rpm, (b) 200 rpm and (c) 300 rpm.

most significant factor affecting starch gelatinization during extrusion, followed by feed rate and screw speed (Table 3). Interaction of barrel temperature with feed rate and with screw speed was also found to be significant.

The influence of barrel temperature and feed rate on percent gelatinization at constant screw speeds are given in Fig. 2. Starch gelatinization increases with increase in the barrel temperature. However, this increase is less dramatic at high feed rates, which possibly shows a minimum residence time needed for gelatinization. With an increase in barrel temperature hydrogen bondings would be disrupted to a greater extent so that more amylose would be solubilized increasing the degree of gelatinization. Increasing feed rate does not change the degree of gelatinization at relatively low barrel temperatures. At low barrel temperatures the possible changes in starch gelatinization at different feed rates may not be obvious since the temperature of the barrel may not be high enough to cause much starch gelatinization. It was observed during tarhana extrusion that an increase in feed rate reduces the mean residence time at a given screw speed (59–135 s), which could reduce the gelatinization due to a shorter processing time (Anderson *et al.*, 1969). Response surface plots showed that increasing screw speed resulted in an increase in percent gelatinization. This could be due to enhanced mixing and shearing effects caused by higher screw speeds (Kokini, 1993). It was observed during extrusion runs that increasing the screw speed usually resulted in an increase in tarhana temperature (data not shown) indicating viscous dissipation which could cause greater gelatinization. As in the case of temperature, hydrogen bondings could be weakened by mechanical action of the screws, which could enhance the leaching of amylose out of the starch granules thereby increasing gelatinization.

CONCLUSION

The results showed that barrel temperature had the most pronounced effect on the degree of starch gelatinization during extrusion at constant moisture content of tarhana. Feed rate and screw speed were found to affect starch gelatinization to a lesser extent. High barrel temperatures and screw speeds, and low feed rates were found to favour starch gelatinization during extrusion. As starch gelatinization is an important factor for instant properties of cereal-based products, studies are currently underway to assess the effect of the degree of starch gelatinization on the consumer acceptability of tarhana soups prepared using extruded tarhana powders. Further studies will also be conducted to investigate the effect of the extrusion process on nutritional properties of extruded tarhana.

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