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Critical Processing Factors in Desolventizing-Toasting Soybean Meal for Feed

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ABSTRACT

Even though it is well established that both underheated and overheated meals are of inferior nutritive value, comparatively little is known of the fundamental nature of the changes brought about in the protein and how these correlate with the processing conditions during toasting. In the present study we examined the interrelation of several factors in the commercial desolventizing-toasting process for toasting soybean meal and determined how these relate to protein quality of the meal. A total of 48 test runs were made in the pilot plant from two cultivars of soybeans (one high and one low in protein) that were dehulled, flaked, and defatted in a continuous extractor using hexane. The solvent-wet flakes were desolventized and toasted under a variety of conditions. In a simulation of commercial operation, independent variables such as moisture, temperature and time of toasting were mathematically converted to equations for computer fitting of the data, which were used to predict several dependent measurements. Quality of the meal was improved by increasing heating time, jacket steam pressure and moisture content. Moisture level in the toasting operation was directly affected by the hexane level in the feed material to the toaster.

INTRODUCTION

Solvent extraction is the preferred method for processing soybeans; more than 90% of the soybeans crushed in the U.S. are handled by this procedure. The most sensitive step in the process for controlling protein meal quality is the desolventizing-toasting (D-T) operation. During the past few decades, the heating or toasting of soybean meal to improve nutritional value has been studied, but little work has been reported with a commercial D-T.

Design and operation of the D-T has been reported by Kruse (1,2), Cravens and Sipos (3), Sipos and Witte (4) and Milligan (5). A preliminary study on a pilot-plant D-T process has been reported by Moulton et al. (6). A major consideration during the various processing steps of desolventizing-toasting is the relationship between time, temperature and moisture, and the effect of that relationship on protein denaturation and protein quality.

The purpose of this study was to define the processing steps and conditions that control nutritional quality. These conditions become important upon translation to D-T operations in the soybean industry. Working with two soybean cultivars in a series of 48 experimental runs, we determined conditions for toasting soybean meals to low urease activity and trypsin inhibitor levels. Other quality criteria such as nitrogen solubility index, available lysine and meal color were also studied.

EXPERIMENTAL

Milling and Extracting

Two soybean cultivars, namely Essex and York, were grown in Maryland and supplied by the University of Maryland for the tests. The beans were milled and extracted for oil at a rate of 50 lb/hr according to the flow procedures shown in Figure 1. The soybeans were cracked through 6 in. diameter (15.24 cm) corrugated rolls set for 0.075 in. (0.19 cm) clearance. As the cracked beans passed onto the double screen shaker, the hulls were removed by an aspirator and collected. The larger pieces of cracked soybeans passing over the top screen [3/16 in. (0.48 cm) perforated round hole] of the double screen shaker were recycled into the cracking process. Bottom screen was 14-mesh black wire screen. The dehulled beans (meats) retained on the bottom screen passed to the tempering conveyor, where they were heated to 165 F (73.9 C) by indirect steam. Tempered meats were flaked through 12 in. (30.48 cm) diameter smooth rolls to a thickness of approximately 0.010 in. (0.025 cm).

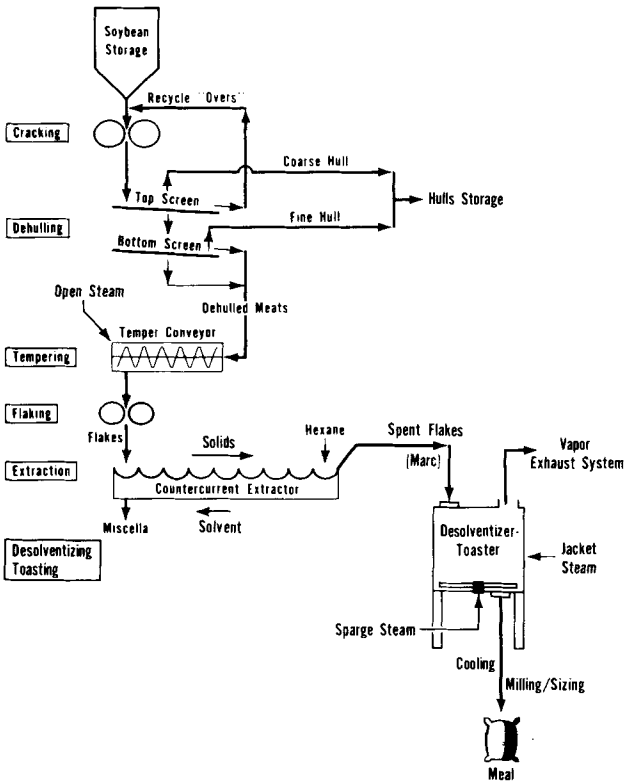

FIG. 1. Flowsheet of pilot plant operations.

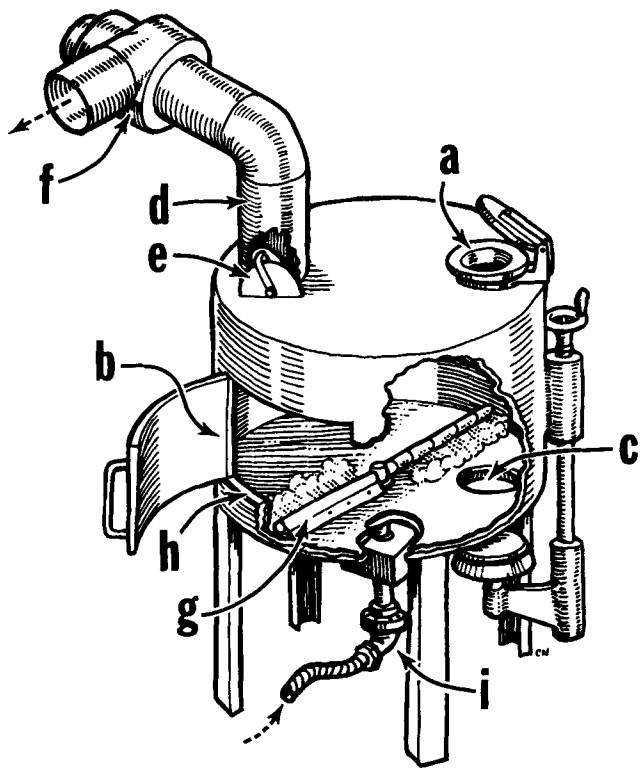

FIG. 2. Pilot plant desolventizer-toaster.

The oil was extracted from the flakes with commercial-grade hexane (2:1 hexane/flake weight ratio) preheated to 140 F (60 C) in a countercurrent immersion-type extractor (7) that has 20 extraction stages. Extraction time was ca. 60 min. The oil-free spent flakes (marc) were drained on an inclined conveyor before they were discharged into the pilot plant desolventizer-toaster (D-T).

Desolventizing-Toasting

The pilot plant D-T shown in Figure 2 is a cylindrical, jacketed 316 stainless-steel vessel with bottom-driven variable speed sweep. Inside dimensions are: 30 in. (76.2 cm) diameter by 20 in. (50.8 cm) high. The access doors located on top (a), side opening (b), and discharge port (c), are vapor tight. Solvent vapors and moisture exit through a 5 in. (12.7 cm) duct (d) fitted with a vent butterfly valve (e) and an exhaust fan (f). The vent, when closed, forms a nearly vapor-tight vessel. The sweeps (g) were fitted with 3-1/2 in. (8.9 cm) high blades at 60° angles on the leading edge and perforated pipe for steam sparge on the trailing edge. The jacket (h) on the sides and bottom was either heated by process steam or cooled by water. Sparge steam, either at 50 psig or at 100 psig, entered the D-T chamber through a rotary valve seal (i) coaxially located on the sweep drive shaft.

Iron-constantan thermometers were located in the unit to measure the meal temperature, vapor temperature and jacket steam temperature. During the toast-drying period, jacket steam pressures of 20 psig and 40 psig were used to effect a significant spread in temperatures. After drying, the meal was cooled rapidly with jacket-cooling water to arrest further heat treatment of the meal.

Before introducing the process sparge steam to the flakes in the D-T, the sparge line was heated and dried by purging with steam. A water separator, installed immediately upstream from the D-T, minimized the amount of entrained water in the sparge steam.

Several preliminary runs were made to establish operational conditions and limits for processing hexane-wetted soy flakes in the pilot plant D-T; i.e., (i) handling hexane-flake mixtures; (ii) hexane-flake moisture relationship; and (iii) minimization of meal agglomeration. The spent flakes were charged into the D-T until a 70-lb (dry basis) batch of material was collected (exhaust fan off and vent closed). The flakes were then stirred slightly and a sample was withdrawn to determine its hexane content.

The amount of moisture added to the defatted soy flakes prior to toasting was dependent on the condensation of water on the flakes from sparge steam. Since the solvent on the flakes boils at a lower temperature than the condensing temperature of the steam, injected steam condenses on the flakes during the sparge and furnishes the heat required to vaporize the solvent. Excess steam then condenses to increase the moisture level, as indicated in Figure 3. The graph shows the linear relationship found between the hexane content of spent flakes fed to the D-T (before steam sparge) and moisture content at end-of-sparge resulting from condensation of sparge steam. It was decided to adjust the hexane concentration in the flakes to either ca. 26% or 39% (mean values) to give a wide range of end-of-sparge flake moistures.

In addition, another procedure was used to increase the spread in moisture range. The flakes were either precooled to 80 F (for high moisture after sparge) or they were preheated to 135 F (for low moisture after sparge). A typical run was then started. Live sparge steam was introduced into the spent flake charge while stirring at 33 rpm (jacket steam at 20 psig). The vent was opened and the exhaust fan was started. Ten seconds after the indicated meal temperature reached 212 F, the sparge steam was stopped, stirring speed was increased to 60 rpm, and the jacket pressure was adjusted to a predetermined level for toasting. Toast-drying of the meal continued under these conditions for the time

specified for the test, after which the steam to the D-T jacket was replaced with cooling water. When the meal temperature fell below 125 F (after about 10 min) the meal was discharged and reduced in size to sieve analysis simulating the sizing of commercial meals (< 30% on 16 mesh, < 5% on 100 mesh). If the meal moisture of the discharged product was greater than 12%, the meal was air-dried to less than 12%.

This D-T experiment was designed to examine the effect of the following variables at indicated levels: (i) end-of-sparge moisture—two levels, 16.3 and 21.5% mean values (attained through hexane levels of 26 and 39% respectively); (ii) toast-dry temperature—two levels of jacket steam attained by controlling at levels of 20 and 40 psig respectively; (iii) toast-dry time—three levels attained by controlling toast-dryout periods at 20, 35 and 50 min respectively; (iv) sparge steam pressure—two levels, 50 and 100 psig; (v) soybean cultivars—two protein levels: York = 35.5% protein, Essex = 39% protein.

All possible combinations of these factor levels leads to an experiment with 48 runs conducted in random order. Standard methods of statistical analysis were followed (8).

Methods of Analysis

The official and tentative methods of the AOCS (9) were used to measure protein, ash, crude fiber, urease activity, nitrogen solubility index (NSI) and sieve analysis. Available lysine was measured by the method of Rao et al. (10). Crude fat was analyzed by AACC Cereal Laboratory methods BC 3-49 (11). Trypsin inhibitor values were assayed by the procedure of Hamerstrand et al. (12).

Solvent concentration of the defatted hexane-wet flakes was determined by weighing the flakes before and after drying under ambient conditions until odorless. The amount of moisture in the spent flakes after sparging was determined by the weight difference in a forced-draft oven at 105 C, according to the 72-hr AACC oven method (11). The amount of moisture in the toasted meal directly after discharge was determined by an O'Haus moisture tester (13), whereas the amount of moisture present after air drying these same meals was determined by a Brabender moisture tester (14).

Color value of the toasted meal was measured by a Hunter color difference meter, model D-25. The total color difference, ΔE, was computed from the difference in values on the L, a and b scales for the parent soybeans and the toasted meal, according to the following relationship:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$

where L = value for the sample lightness; a = red to green value; and b = yellow to blue value.

RESULTS

Optimization of Toasting Conditions

A typical heating or temperature response curve with time is given in Figure 4. A rise in temperature above 212 F

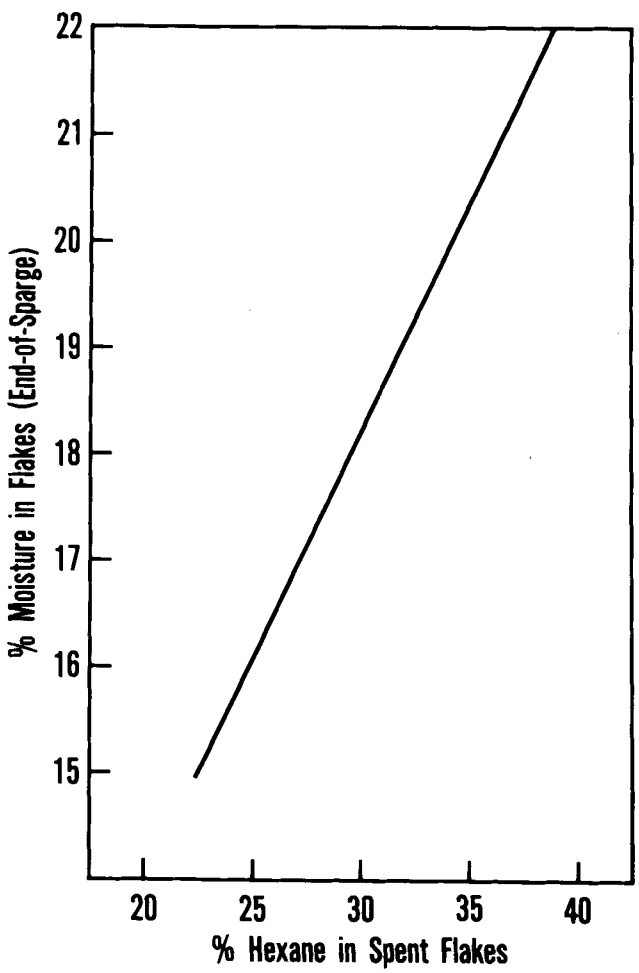

FIG. 3. Residual hexane (spent flakes) vs meal moisture at end-of-sparge.

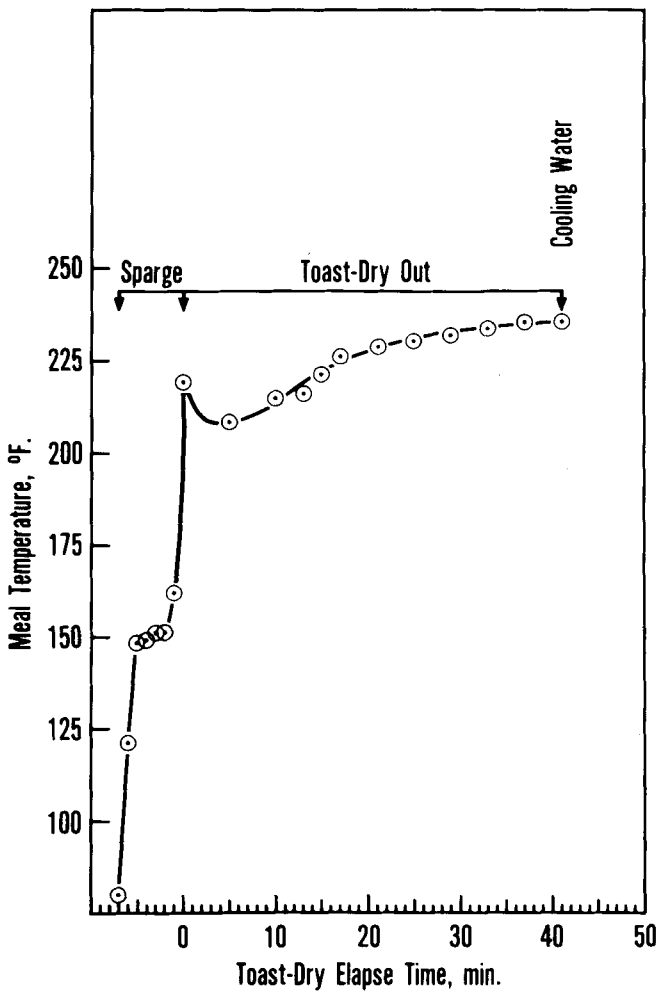

FIG. 4. Typical time-temperature heating curve.

TABLE I

Processing and Analytical Data–Essex Cultivar

Run no.	Spent flakes fed to D-T % hexane after[a] adjustment	Sparge conditions: Steam press (psig)	Sparge conditions: Time interval (min)	Sparge conditions: Moisture at end of sparge (%)[b]	Toasting conditions: Jacket press (psig)	Toasting conditions: Steam temp (F)	Toasting conditions: Time interval[c] (min)	Toasting conditions: Temperatures Min. (F)	Toasting conditions: Temperatures Max. (F)	Analytical: Urease act. pH change	Analytical: NSI (%)	Analytical: Avail. lysine % of protein	Analytical: TI (mg/g)	Hunter color value (ΔE)
Untreated raw flakes										2.1	88		42	
Defatted flakes										2.1	61		23	
1	41	50	6	23.9	40	297	35	221	244	0.03	24	–	3.3	11.5
2	38	50	5	21.8	20	270	35	207	241	0.27	16	–	2.6	13.1
3	27	100	2	10.8	40	300	35	198	248	0.35	19	–	3.7	12.3
4	37	100	3	13.9	40	300	20	217	238	0.20	33	6.2	4.3	10.7
5	38	100	3	20.9	20	267	20	210	235	1.61	40	6.2	5.2	11.4
6	27	100	2	16.8	20	268	20	212	239	1.92	45	–	8.5	8.7
7	25	50	3	16.6	40	300	35	208	247	0.36	19	–	4.1	12.3
8	26	100	2	17.8	40	298	20	213	246	1.04	27	6.2	6.1	10.2
9	39	100	3	21.6	40	300	35	212	247	0.02	17	–	2.8	15.8
10	27	50	3	16.4	20	262	50	197	250	1.36	22	6.2	6.1	11.2
11	39	50	6	21.8	40	300	20	212	243	0.33	35	6.2	5.7	10.5
12	38	100	3	24.3	40	298	50	212	252	0.02	18	6.1	2.7	14.8
13	28	100	2	17.3	20	267	35	216	244	1.24	26	–	4.8	12.3
14	26	50	3	17.0	40	298	50	218	251	0.17	11	6.1	2.7	16.3
15	27	50	3	16.6	20	267	20	216	246	1.83	37	6.2	8.2	9.9
16	38	100	3	23.1	20	266	50	210	234	1.05	22	6.2	4.6	13.6
17	25	100	2	17.5	40	300	50	228	252	0.15	11	6.2	2.9	16.6
18	40	50	6	21.8	20	263	50	213	243	0.11	22	6.2	3.4	12.7
19	25	100	2	16.8	20	268	50	217	248	0.45	18	6.1	3.7	14.4
20	26	50	3	15.8	40	300	20	193	250	1.18	30	6.2	7.7	11.2
21	40	50	6	21.7	40	298	50	214	253	0.05	15	6.0	1.6	18.1
22	38	50	6	21.0	20	267	20	203	227	1.97	45	6.2	8.3	10.1
23	25	50	3	15.9	20	268	35	198	243	1.69	29	–	7.5	10.6
24	39	100	4	21.6	20	268	35	217	245	0.21	22	–	3.6	14.0

[a]26.2% = mean value for low hexane level; 38.7% = mean value for high hexane level.
[b]16.3% = mean value for low hexane level; 21.5% = mean value for high hexane level.
[c]Elapsed time after sparge to cooling period.

during a short interval at the end of sparge reflects a steam effect rather than true meal temperature. A meal sample withdrawn and analyzed for moisture at the end of sparge gave 21.5% (based on 39% hexane in the D-T feed flakes). During the toasting-dryout period, meal temperatures rose gradually as drying out was accelerated by venting; final moisture at the end of toasting was approximately 14%. The meal was then cooled rapidly and air-dried to a final moisture of 10.7%.

Table I shows the detailed process data obtained for one of the cultivars (Essex) for the 24 runs; similar data were also obtained for the York cultivars but are not included. Equations were fitted to the urease activity, trypsin inhibitor (TI), nitrogen solubility index (NSI), and meal color. The independent variables, as previously noted, were hexane content of feed to D-T (reflected as moisture), steam jacket pressure (reflected as temperature), time of toasting and steam sparge pressure. The analysis of variances indicated that sparge pressure (50 vs 100 psig) did not produce an effect and did not interact with other factors. Also, the effect of protein level in each cultivar did not result in any response effect.

A statistical analysis of the response data for significant effects was made using the independent variables listed above with the additional variable of cultivar type (Essex, York) included. Table II shows both significant main effects and interactions based on analysis of variance of the data. All variables listed above had a direct effect on urease activity and TI. Nitrogen solubility was affected only by jacket steam pressure and toast time, whereas Hunter color values were influenced by all the variables except types of cultivar. Significant two-way interactions are listed for urease activity and TI, whereas three-way interactions were found for NSI and Hunter color values. Cultivar responses resulted in significant variations with urease activity and TI values.

Original TI values for the raw bean cultivars were 42 mg/g for Essex and 30 mg/g for York. It is conceivable that the initial TI differences or ratios influenced the results and perhaps were reflected in the residual TI responses at the end of the toasting period.

Denaturation prior to toasting. Comparative data for the untreated raw flakes and defatted flakes prior to toasting indicate there was a drop in the nitrogen solubility index (88 → 61) and the TI (42 → 23) during bean preparation and solvent extraction. Since some live steam was used in the preconditioning for dehulling meats prior to flaking (Fig. 1), it is quite likely that this was the source of some denaturation.

Urease activity. It is generally believed to be desirable to provide sufficient heat treatment to inactivate the urease enzyme in soybeans. Mixed feed manufacturers generally consider that a meal having a urease activity of less than 0.1 pH rise by the Caskey Knapp method is satisfactory for

TABLE II

Significant Effects and Interactions Based on Analyses of Variance

Independent variable	Response Data: Urease Activity pH change	TI (mg/g)	NSI (%)	Hunter color value (ΔE)
		Main effects means		
Hexane level				
26%	0.81[a]	4.52[a]	24.5	11.9[a]
38%	0.32	3.36	24.5	13.5
Jacket steam pressure (toast)				
20 psig	0.82[a]	4.35[a]	27.5[a]	12.2[a]
40 psig	0.32	3.53	21.4	13.2
Toast time				
20 min	0.97[a]	5.42[a]	35.1[a]	10.4[a]
35 min	0.36	3.38	21.4	12.8
50 min	0.37	3.02	16.9	14.8
Cultivar				
Essex	0.73[a]	4.75[a]	25.1	12.8
York	0.40	3.12	23.8	12.6
		Interactions		
	BD	BD	ACD	BCD

[a]Significant variation between means in this series (.05 level).

most formulations involving urea. Original urease activity values for the raw bean cultivars were 2.1 for Essex and 2.0 for York.

Figure 5 shows response contours of predicted urease activity as influenced by hexane content, jacket steam pressure and time (Essex cultivars). Solid line contours of constant response are used for the low hexane level of 26% (16.3% moisture, mean equivalent) and the dotted lines are contours for the high hexane level of 39% (21.5% moisture, mean equivalent). The multiple correlation R between observed and predicted urease activity was R = 0.93. Based on these curves, it appears that time, temperature and moisture level all have a direct influence on the reduction of urease activity to low levels. One can optimize the reduction of urease by any combination of the independent variables shown.

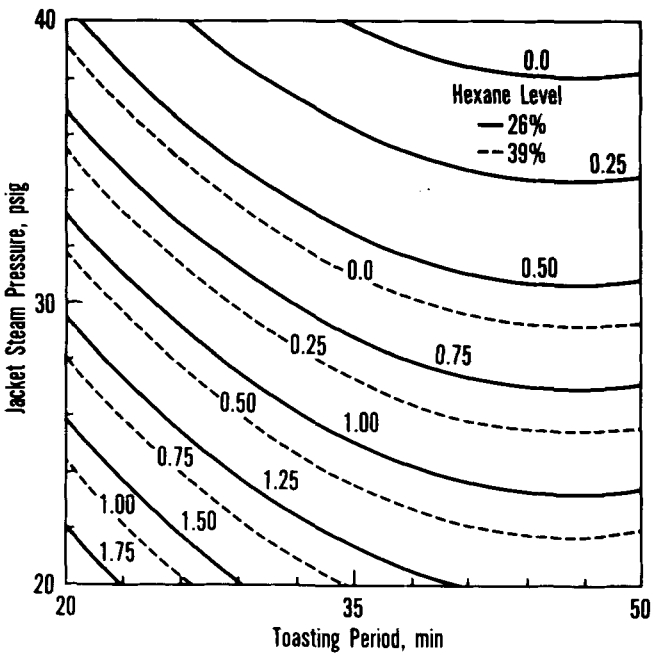

FIG. 5. Urease activity (pH change) as influenced by hexane level, jacket pressure and time.

Trypsin inhibitors. The role of natural protease inhibitors in physiological and pathological reactions in man and animals has been reviewed (15,16). The TI data for Essex soybeans are listed in Table I. The observed TI values were analyzed and used to develop the response curves shown in Fig. 6. The curve responses are somewhat similar to those for urease activity and reflect the same dependency on time, temperature and moisture. The multiple correlation between observed and predicted TI was 0.89.

TI inactivation is most effective at the high levels of jacket steam pressure and time in the D-T. Also, at the higher hexane level (dotted lines), the additional moisture produces a significant improvement in the rate of inactivation. Low residual levels in the range of 2-4 mg/g TI were reached at high levels of heat, time and moisture. Since commercial toasting specifications generally require that urease activity be reduced to 0.1 pH unit change or less, contours at constant 0.1 urease activity were drawn directly on the TI curves to indicate what levels of TI were attained under comparable treatment conditions. Curve 1 indicates the contour for 0.1 urease activity where the hexane level was 26%, whereas curve 2 indicates conditions where the level was 39%. It appears that when a urease level of 0.10 is achieved for either initial hexane concentration, then TI levels will be reduced to the range of 2-5 mg/g.

Nitrogen Solubility Index. The nitrogen solubility index of toasted meals is an important indicator that relates to the degree of toasting and nutritional quality. Generally, NSI values of 15-20 have corresponded to toasting of soybeans to low urease activity of 0.05-0.15, whereas NSI values under 10 generally indicate overtoasting (Hayward, 17). The NSI values as influenced by jacket steam pressure and time of toasting (Essex cultivar) are shown as contours in Figure 7. The multiple correlation was R = 0.93. When conditions of toasting were suitable to give low urease and TI values, a range of 15-20 NSI was obtained (Fig. 5,6,7) with 26% hexane and after 35 min toasting with 39% hexane.

Hunter meal color. The degree of meal darkening during

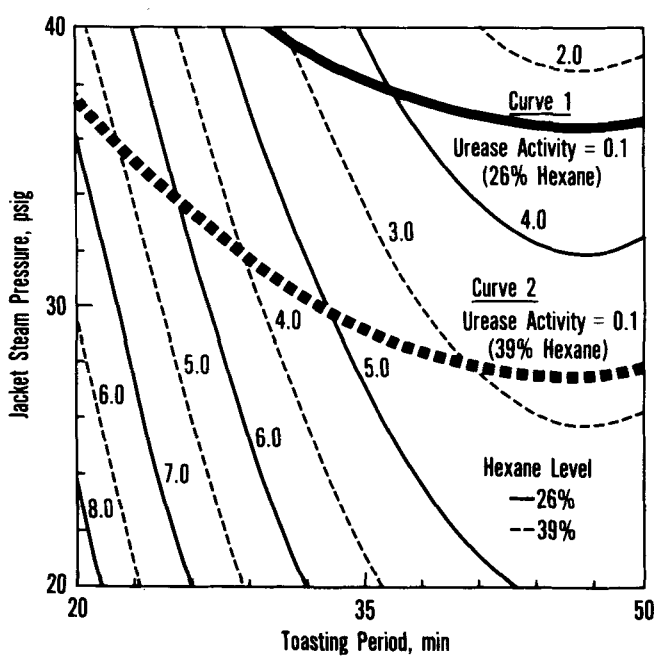

FIG. 6. Residual trypsin inhibitor (mg/g) as influenced by hexane level, jacket pressure and time.

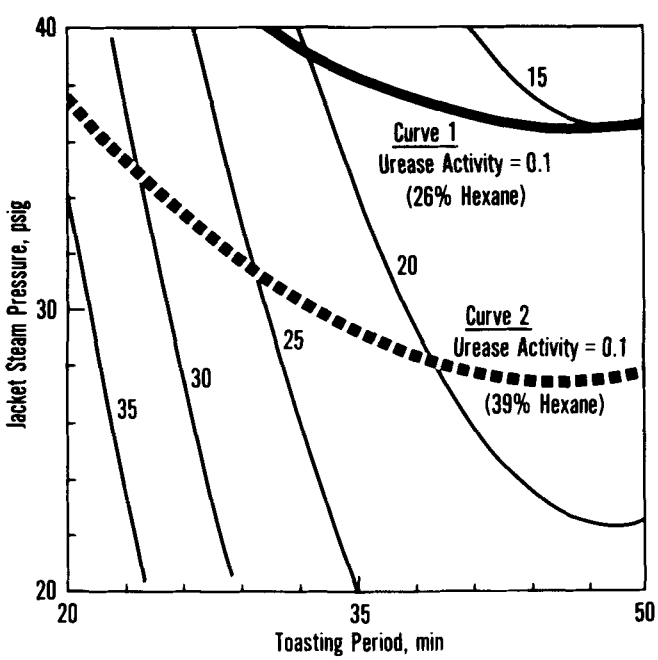

FIG. 7. Nitrogen solubility index (%) as influenced by jacket pressure and time.

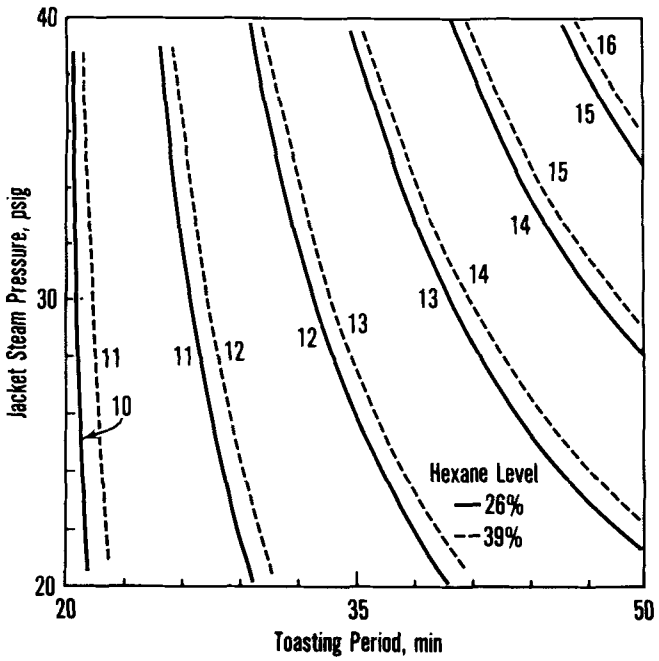

FIG. 8. Hunter meal color (ΔE) as influenced by hexane level, jacket pressure and time.

toasting in terms of ΔE color values was found to correlate with D-T process conditions as did urease, TI and NSI; Figure 8 shows these variations of ΔE values for the Essex cultivar over a range of 10-16 as influenced by hexane level, jacket steam pressure and toasting time, R = 0.88. Time of toasting appears to have the most pronounced effect on meal darkening, whereas the higher hexane level yields a slightly darker product. When meal color values were plotted against residual trypsin inhibitors, a fairly good linear relationship was obtained, as shown in Figure 9, probably indicating that both TI and meal color values respond equally to toasting time.

Available lysine. The range of assays for available lysine (6.0-6.2), given in Table I, indicates there was relatively little to no destruction from the original value of the raw bean (6.1) .and that there was little variation due to processing conditions as carried out in this study.

Criteria for toasting controls. Residual enzymes, protease inhibitors, protein solubility and meal color are indexes that reflect the quality of soybean meal during and after the toasting process. This paper has presented the results of a pilot-plant experimental study in which such independent variables as moisture, temperature and time were found to be critical factors in the toasting process. This type of information will be useful in establishing new specifications in meal quality through better process control. In addition, it will enable us to prepare pilot plant quantities of soybean meals under simulated industrial conditions for use in nutritional studies.

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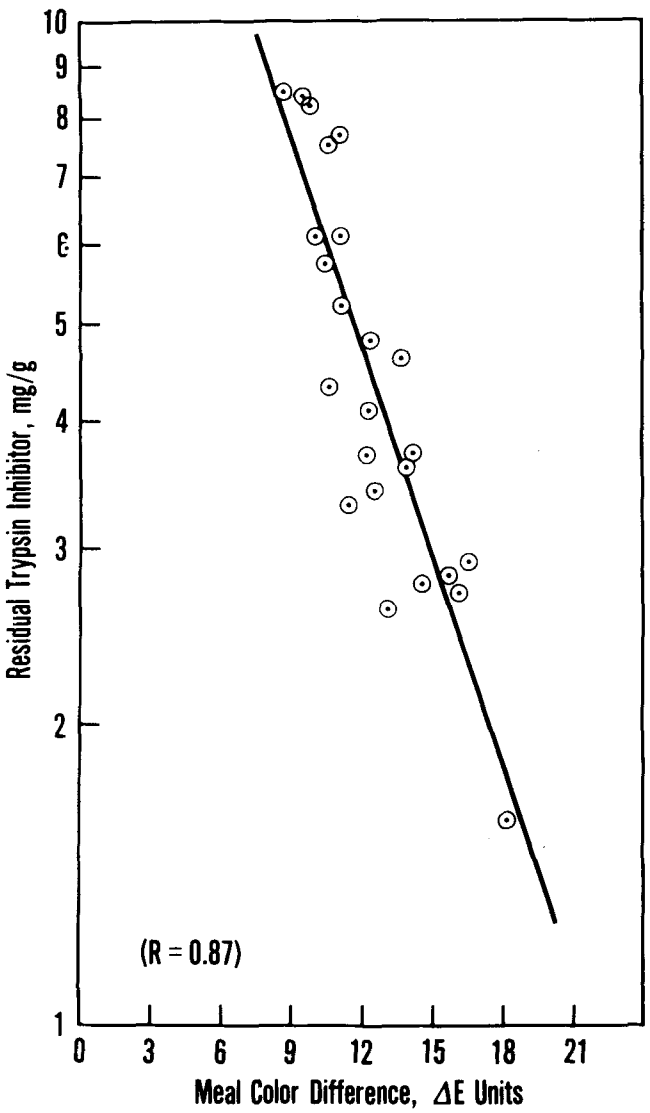

FIG. 9. Relationship of trypsin inhibitor to Hunter meal color values in toasted meals.

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