Functional Properties of the Total Proteins of Sunflower (*Helianthus annuus* L.) Seed—Effect of Physical and Chemical Treatments

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The effect of wet heating, dry heating, and washing with acidic butanol on nitrogen solubility profiles, functional properties such as foaming indices and emulsification indices, and other related parameters is investigated in water and 1 M NaCl extracts from dehulled, defatted, and powdered samples of sunflower seeds. The results show that autoclaving at 2 kg/cm^2 and roasting at both 100 and 150 °C affect nitrogen solubility of the proteins in water and 1 M NaCl. The foam volume indicates a decrease as a result of acidic butanol treatment, whereas it decreased by 40% in the untreated sample. Foam from samples roasted at 150 °C or autoclaved at 1 and 2 kg/cm^2 collapses faster during a period of 120 min as compared to the sample roasted at 100 °C and the control. The emulsification stability was higher in water for all samples as compared to those in sodium chloride solution. The results are explained on the basis of surface properties and physicochemical properties of sunflower seed proteins.

INTRODUCTION

Sunflower seed, mainly grown for oil, is a promising source of vegetable proteins. The polyphenol chlorogenic acid binds to proteins and reduces the nutritional value. Hence, methods have been developed to remove the polyphenols. Defatted meal and protein concentrate have good functional properties (Sosulski and Fleming, 1977) but are devoid of the property of gelation (Sosulski, 1979). Proteins are incorporated into food systems to enhance the nutritional value of the product or to improve its acceptability (Kinsella, 1976). Functionality of the proteins includes properties such as bulk density, water absorption capacity (WAC), fat absorption capacity (FAC), foaming properties such as foam capacity (FC) and foam stability (FS), and emulsification properties such as emulsification capacity (EC), emulsification stability (ES), and emulsification activity (EA). On the basis of their functionality, the proteins find use in diverse systems such as fabricated and texturized food products. However, processing conditions such as heat and pressure during oil extraction and acidic butanol treatment (Sodini and Canella, 1977) to remove chlorogenic acid could alter the functional properties of proteins.

Changes in properties, as a result of heat, pressure, and acidic butanol treatment, arise due to changes in the association–dissociation and denaturation phenomena of proteins as well as surface properties such as surface charge density and hydrophobicity-related properties (Mattil, 1971). All of these changes would result in a significant change in the solubility profile of the protein also, with concomitant changes in the functionality of the proteins.

The object of this study was to evaluate changes in the functional properties of the proteins such a nitrogen solubility, bulk density, water and fat absorption capacities, foaming capacity and stability, and emulsion capacity resulting from physical and chemical treatments of the seed.

MATERIALS AND METHODS

Sunflower seeds, *Helianthus annuus*, were purchased from National Seed Corp., India.

The chemicals used were from the following sources: Sodium dodecyl sulfate was from Sigma Chemical Co., St. Louis, MO. Sodium hydroxide was from Astra IDL, Bangalore, India, and refined peanut oil (Postman brand) was from M/s Ahmed Oil Mills, Bombay, India. All other chemicals used were of analytical reagent grade.

Processing of Seeds. Sunflower seeds were graded, cleaned, and divided into five batches. One batch without any treatment served as control. Two batches were dry-roasted in a rotary roaster (M/s Bharat Co., India) at 100 and 150 °C and designated R_1 and R_2, respectively. Times for the seeds to reach the specified temperatures were 20 and 25 min, respectively. The seeds were cooled by aeration. The seeds had an initial moisture content of 9.5% before roasting, and the final moisture contents were 5.2 and 5.0%, respectively, for the 100 and 150 °C roasted samples. The temperature in the core of the seed was measured using a temperature probe. The remaining two batches were wet-heated by autoclaving at 1 and 2 kg/cm^2 for 25 min in a Conrad Engelke, Hannover-Limmer autoclave. The seeds reached temperatures of 121 and 143 °C at 1 and 2 kg/cm^2, respectively, and were designated A_1 and A_2. The seeds were cooled and dried at 50 °C for 20 h in an Armstrong Smith (India) cabinet dryer with capacity of 40 trays of 400 mm × 800 mm. The final moisture contents of the seeds were 5.9 and 5.5%, respectively, for the 1 and 2 kg/cm^2 autoclaved samples. The acidic butanol washing of the defatted sunflower and flour was carried out by a minor modification of the method described by Sodini and Canella (1977). The flour was washed seven times with acidic butanol, pH 5.8, and with every washing the absorbance of the eluent was monitored at 325 nm for tracking polyphenols. After six washings, the polyphenol content was reduced by 95% as compared to the control. An additional washing was done to ensure removal of most of the polyphenols. A holding time of 3 h was used for each washing at a temperature of 20 °C.

Preparation of Flour. All five batches of sunflower seeds were separately dehulled in a centrifugal sheller with aspirator. They were flaked in a rice flaker and were solvent-extracted eight times with *n*-hexane to a final fat content of less than 1%. The grits were then dried in the cabinet dryer for 4 h and powdered in a Brabender Quadramat-Senior automatic pilot mill to obtain fine flour of less than 150 μm size. Fresh flour thus prepared was used for all further studies.

Nitrogen Solubility. Nitrogen solubility was determined according to the method of Mattil (1971), and nitrogen was estimated according to Kjeldahl method (AOAC, 1984). The soluble nitrogen was calculated as total nitrogen and expressed as percent of the total nitrogen in the flour. Ammonium sulfate was used as the standard for quantitation of nitrogen.

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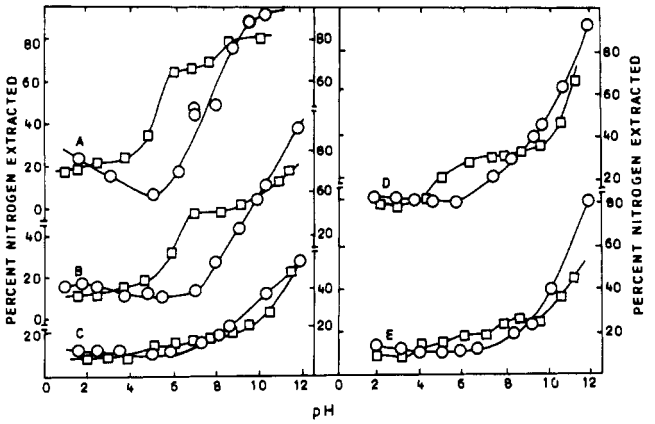

Figure 1. Percent nitrogen extracted as a function of pH of sunflower seed total proteins from the defatted flours (○) in water and (□) in 1 M NaCl. Samples: (A) Untreated total proteins; (B) roasted at 100 °C; (C) roasted at 150 °C; (D) autoclaved at 1 kg/cm^2; (E) autoclaved at 2 kg/cm^2.

Functional Properties. Water absorption capacity was determined according to the method of Sosulski (1962) and was expressed as the amount of water absorbed by 100 g of the material. Fat absorption capacity of the meal was measured according to the method of Sosulski et al. (1976) and is expressed as the amount of oil (milliliters) bound by 100 g of meal.

Foam Measurements. One hundred milliliters of distilled water was added to 3 g of defatted sunflower seed flour and the mixture homogenized at 3000 rpm for 5 min in a Virtis homogenizer at 27 °C and transferred to a measuring cylinder. The volume of foam at 30 s was calculated, and the volume increase is expressed as percent foam capacity. The foam stability was determined by measuring the decrease in volume of foam as a function of time up to a period of 30 min. Foam density is the volume of foam divided by weight.

Emulsion Measurements. Emulsification capacity was determined according to the procedure of Beuchat et al. (1975) and is expressed as milliliters of oil emulsified per gram of protein. Emulsification activity was determined according to the method of Pearce and Kinsella (1978).

Thirty milliliters of distilled water and 10 mL of refined groundnut oil were added to 1.5 g of flour, and the mixture was stirred. The contents were homogenized in a Virtis homogenizer at 2000*g* for 1 min. An aliquot of 0.1 mL was drawn immediately and at regular intervals of time from the bottom of the container and diluted to 10 mL with 0.1% sodium dodecyl sulfate; the absorbance was measured at 500 nm in a Beckman DU 8B spectrophotometer. To measure the absorbance, the emulsion is diluted so as to read within 1.0 absorbance in a spectrophotometer; the reading is multiplied by a dilution factor, for example, 30, and the resulting absorbances (such as 30, 36, 28) are plotted on the *Y* axis. A graph of absorbance against time was plotted. The time for the initial absorbance (emulsification activity) to decrease by half was recorded as emulsification stability.

RESULTS

The nitrogen solubility profiles of the total proteins of sunflower defatted flour (control) extracted in water and in 1 M NaCl at pH values from 1 to 12 are shown in Figure 1A. Total proteins show a U-shaped curve and have a solubility minimum at pH 5.0.

Nitrogen solubility profiles of the total proteins of the various dry-heated and autoclaved samples, determined in water and 1 M NaCl, are also shown in Figure 1B–E. The R_1 sample does not show a solubility minimum like the control protein in water (Figure 1A), whereas the solubility profile in NaCl is similar to that of the control protein, indicating a partial denaturation of the water-soluble proteins below pH 5.0. The R_2 sample has no defined minimum in either 1 M NaCl or water, and only 53% of the protein is extractable at pH 12.0 (Figure 1C).

Table I. Bulk Density, Water Absorption Capacity (WAC), and Fat Absorption Capacity (FAC) of Heat- and Acidic Butanol-Treated Sunflower Seed Defatted Flour

sample[a]	bulk density, g/mL	WAC, %	FAC, %
control (untreated)	0.263 ± 0.021	310 ± 8	286 ± 8
roasted at 100 °C (R_1)	0.282 ± 0.019	313 ± 9	292 ± 8
roasted at 150 °C (R_2)	0.229 ± 0.023[b]	354 ± 10[b]	310 ± 10[b]
autoclaved at 1 kg/cm^2 (A_1)	0.271 ± 0.024	335 ± 11	270 ± 10
autoclaved at 2 kg/cm^2 (A_2)	0.246 ± 0.021[b]	353 ± 12[b]	291 ± 11
acidic butanol-treated (AB)	0.284 ± 0.019	210 ± 8[b]	130 ± 6[b]

[a] Based on three replicates. The values are means ± standard deviation. They are significantly different from the untreated control at $p < 0.05$. [b] Data significantly different from the untreated control at $p < 0.01$.

The water extract of autoclaved sample A_1 has a solubility profile similar to that of R_1 with a 50% reduction in solubility at neutral pH with a more extended plateau region from pH 6.0 to 9.5 (Figure 1D); maximum extractability decreased by 15% on autoclaving. In the A_2 sample, there is no minimum in either water or 1 M NaCl and the solubility in the extreme acidic region of pH 2 and the alkaline region shows a significant decrease (nearly 50%) compared to the control (Figure 1A,E). Similar to R_2, the A_2 sample does not show large variation in the extractability profile in either water or sodium chloride.

Bulk density of the control was 0.263 g/mL (Table I). In both the R_1 and A_1 samples, bulk density increased by nearly 7 and 8%, respectively, as compared to the control. The increase could be due to the removal of the residual moisture in the flour, resulting in dense packing of the flour particles for the same unit volume. At higher heat treatments, such as for samples R_2 and A_2, bulk density decreased by 13 and 7% of the control value, possibly due to the puffing of each particle at these high temperatures (Kinsella, 1976). The bulk density of the acidic butanol-treated flour showed an increase when compared to the control. Similar increases in bulk density of solvent-treated seed flours and proteins were observed by other workers (Kinsella, 1976; Wang and Kinsella, 1976; Sripad, 1984).

The water absorption capacity (WAC) is higher in the more severely heat-treated flours, A_2 and R_2, by 1.14 times as compared to either the control or R_1. Similar observations have been made by several workers with other oilseed proteins (Sosulski and Fleming, 1977; Rahma and Narasinga Rao, 1981). The WAC of the acidic butanol-treated flour, when compared with that of the control, decreased significantly (by 0.33 times). Similar observations were reported by Canella et al. (1977). The observed decrease could possibly be due to loss in solubility or due to protein aggregation, thus decreasing the surface area that is exposed to the water phase. The fat absorption capacity FAC of the control flour is 286% (Table I), which correlates well with other studies (Madhusudhan and Srinivas, 1987; Sosulski and Fleming, 1977). Statistical analysis of the FAC of the different samples indicates that R_2 has a higher FAC by 1.1 times, which is significantly different from the control, and acidic butanol-treated flour has a lesser value by 0.45 times as compared to the control. This might be due to aggregation of the protein, which reduces the number of nonpolar residues that are exposed (Kinsella, 1976; Matsudomi et al., 1982; Kato et al., 1983). Rahma and Narasinga Rao (1981) did not observe significant changes in the functional properties of acidic butanol-treated flours. Our values show a large difference in the functional properties as compared to the control. One reason could be that we have performed the washings of the flour to a removal of more than 95% of CGA in the

Table II. Functional Properties of Sunflower Seed Defatted Flours: Control, Heat-Treated, and Acidic Butanol-Treated in Water and 1 M NaCl

property	sample[a] C	R_1	R_2	A_1	A_2	AB
emulsification activity, absorbance at 500 nm						
in water	15.5	12.3	21.3	20.2	26.6	10.9
in 1 M NaCl	20.3	14.3	25.2	20.0	21.9	11.6
emulsification stability, s						
in water	550.0	25.0	20.2	400.0	400.0	300.0
in 1 M NaCl	14.4	14.5	85.0	7.2	7.20	36.0
emulsification capacity, mL of oil/g of flour						
in water	48.8	47.5	38.8	46.0	40.5	32.5
in 1 M NaCl	46.3	45.0	30.8	38.0	33.5	25.3
foam capacity, %						
in water	67	65	68	41	38	55
in 1 M NaCl	73	82	74	49	46	83
foam stability, %						
in water	75	70	68	48	61	65
in 1 M NaCl	70	73	53	70	77	72

[a] C, control; R_1, roasted at 100 °C; R_2, roasted at 150 °C; A_1, autoclaved at 1 kg/cm^2; A_2, autoclaved at 2 kg/cm^2; AB, acidic butanol-treated.

flour, which is equivalent to seven washings of the flour. Perhaps this extensive washing has altered the properties of the protein to a large extent.

The foam capacities of the control and heat- and solvent-treated flours are shown in Table II. The control flour has a value of 67%, and autoclaving markedly decreased the foam capacity, the values being 41 and 38% for A_1 and A_2, respectively, which are significantly different from the control value (Table II). This indicates that changes in foam capacity might be induced by pressure and moisture during processing. However, addition of 1 M NaCl increases the foam capacity of all the flours irrespective of heating temperature, pressure, or moisture during processing. The FC of the acidic butanol-treated flour in water and 1 M NaCl indicates a decrease in water (55%) as compared to control (73%), while it increased in the presence of 1 M NaCl to 83%.

The foam stabilities (FS) of the control and heat-treated flours are shown in Table II. The foam stability of control in water has a value of 45%. Dry-heating decreased the foam stability, the extent depending on the severity of the treatment. The FS of R_2 is significantly lower (11%) than that of R_1 (39%). Autoclaving also decreased the foam stability, but A_1 was lower than A_2, the values being 9 and 13%, respectively. In 1 M NaCl the foam stability decreased in the control to 41% and in the autoclaved samples A_1 and A_2 to 5 and 9%, respectively. However, there was a significant increase in foam stability of the dry-heated samples in the presence of 1 M NaCl with R_1 at 53% being greater than that of the control. Similar observations were reported by other workers as well (Huffman et al., 1975; Canella, 1978). The foam stability of the acidic butanol-treated flour reflects a significant decrease in water as solvent (18%) and an increase in the presence of 1 M NaCl as solvent (51%).

The decrease in foam volume as a function of time of the control and heat-treated flours is shown in Figure 2. Control and R_1 flours have stable foams with only marginal decrease with time (Figure 2). One molar NaCl as solvent decreased the stability of the foam in control. The R_1 sample showed an increase in foam stability in the presence of 1 M NaCl. A_1 and the severely heat-treated, A_2 and R_2, flours showed poor stability of the foams with respect to time (Figure 3). R_2 and A_2 show a steep decline from initial time onward. One molar NaCl decreases the foam stability of A_1 and A_2 and acidic butanol-treated samples. However, in the presence of 1 M NaCl, both R_1 and R_2 show a higher level of stabilization as compared to that in water.

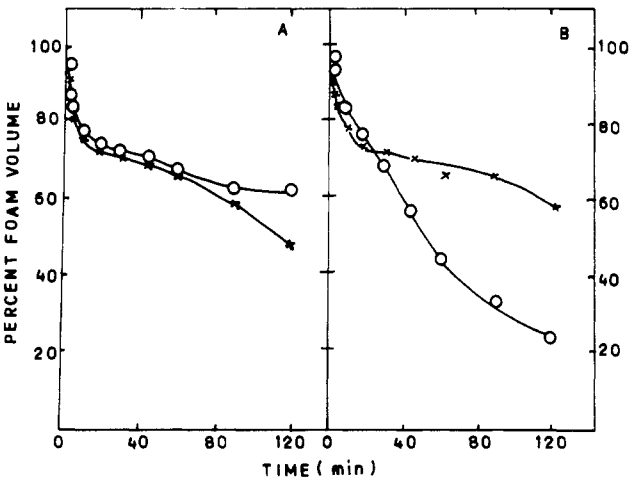

Figure 2. Foam volume as a function of time of sunflower seed total proteins from the defatted flours (O) in water and (×) in 1 M NaCl. Samples: (A) Untreated total proteins; (B) acidic butanol-treated total proteins.

Foam density also shows a trend similar to foam capacity and foam stability, with A_2 having the highest foam density of 0.325 g/mL compared to control, which is 0.261 g/mL. The foam density of the acidic butanol-treated flour is higher (0.280 g/mL) than that of the control. There is only a marginal increase observed in the presence of 1 M NaCl in all of the samples, possibly due to salt being entrapped in the foam matrix.

The emulsification parameter of the control flour was 15.5 in water (Figure 3 and Table II). Dry-heating at 100 °C (R_1) lowered the emulsification activity to 12.3, but it increased significantly at 150 °C. Autoclaving increased the emulsification activity, with A_2 being higher than A_1. The values are 26.6 and 20.2, respectively. Sodium chloride increased the EA of the control to 20.3. R_1 and R_2 also showed increases in EA to 14.3 and 25.2, respectively. The EA of the acidic butanol-treated flour both in water and in 1 M NaCl was lesser (10.9 and 11.6, respectively) than control values in the respective media.

The emulsification stability (ES) of the control and the heat-treated flours shows that the control flour has an ES value of 420 s. Autoclaving increases the stability of A_2 to 540 s, which is higher than that of A_1 (420 s). Dry-heating significantly reduced the ES, and the values are 2.5 and 20 s for R_1 and R_2, respectively. The ES in 1 M NaCl increased in all of the samples, but the extent varied depending on the heat treatment, unlike that observed in water. The control value significantly increased to 1440

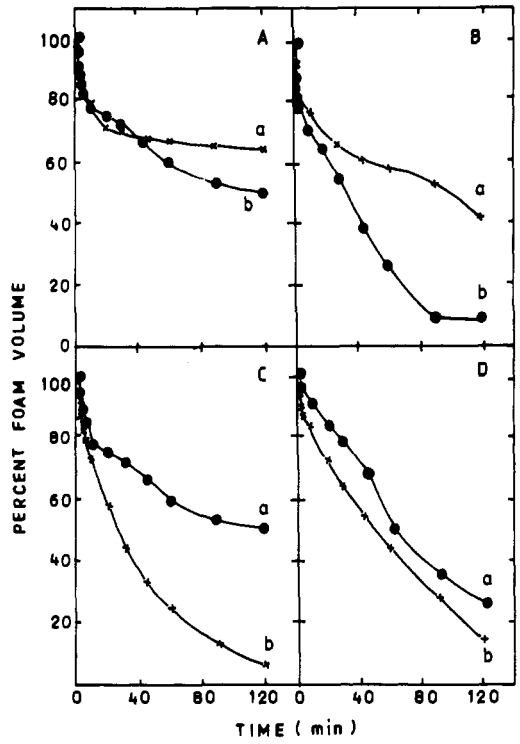

Figure 3. Emulsification stability as a function of time of sunflower seed total proteins from the defatted flours (●) in water and (×) in 1 M NaCl. Samples: (A) Roasted at 100 °C; (B) roasted at 150 °C; (C) autoclaved at 1 kg/cm²; (D) autoclaved at 2 kg/cm². The absorbance at 500 nm is measured (less than 1.0) and corrected for dilution factor and plotted on the *Y* axis.

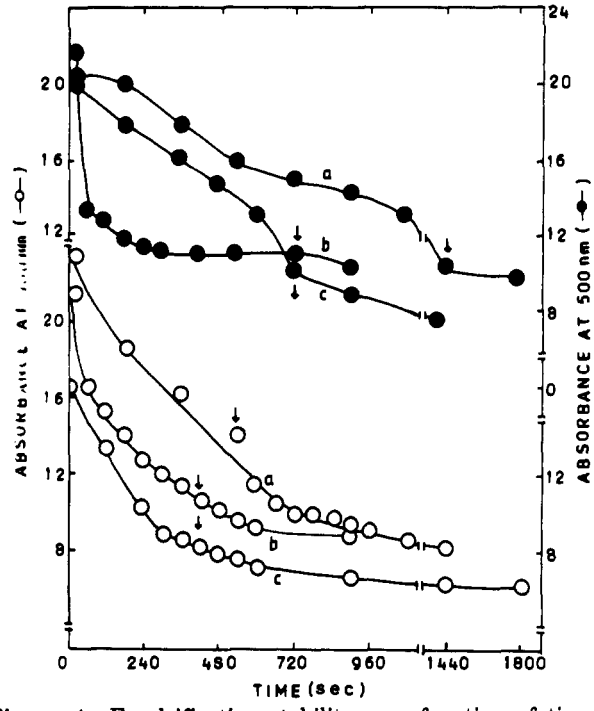

Figure 4. Emulsification stability as a function of time of sunflower seed total proteins from the defatted flours (○) in water and (●) in 1 M NaCl. Samples: (a) Roasted at 100 °C; (b) roasted at 150 °C. The absorbance at 500 nm is measured (less than 1.0) and corrected for dilution and plotted on the *Y* axis. The arrow indicates 50% absorbance of the starting value and is emulsion stability of the sample.

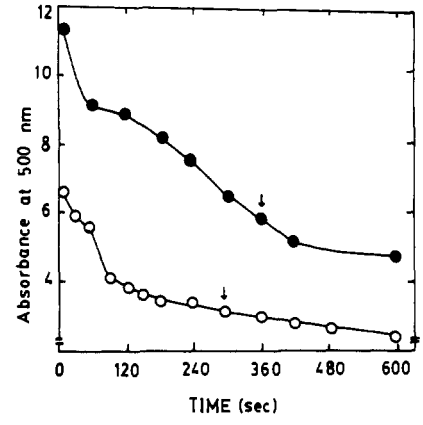

Figure 5. Emulsification stability of sunflower seed acidic butanol-treated proteins from the defatted flours (○) in water and (●) in 1 M NaCl. The absorbance at 500 nm is measured (less than 1.0) and corrected for dilution and plotted on the *Y* axis. The arrow indicates 50% absorbance of the starting value and is emulsification stability of the sample.

s. R_1 was 145 s, and R_2 was 85 s. The A_1 and A_2 samples both had values of 720 s. The acidic butanol-treated flour had ES values of 300 and 360 s in water and 1 M NaCl, respectively.

A graphic representation of ES vs time of the control and heat- and solvent-treated samples in water and 1 M NaCl is shown in Figures 3–5. In water, both control and A_1 samples are similar, while A_2 has a significantly higher ES value (540 s). But R_1 and R_2 fall sharply within 60 s, with R_2 having a lower ES value of 20 s than R_1 (25 s). The ES in the presence of 1 M NaCl increases in all of the samples (Figures 4 and 5), with the autoclaved samples having a static level of 720 s. R_1 shows a higher EC value (145 s) than R_2 (85 s) in the presence of 1 M NaCl. The EC monitored as a fall in absorbance at 500 nm vs time of the acidic butanol-treated flour indicates a gradual fall in water. This stabilizes in the presence of 1 M NaCl, and the fall is reduced.

The emulsification capacity decreased as a function of treated temperature, with control having a value of 48.8 mL of oil/g of flour (Table II). The A_2 and R_2 flours, with EC values of 40.5 and 38.8 mL of oil/g of flour, respectively, show greater decrease in EC as compared to A_1 (46.0) and R_1 (47.5) in water (Table II). The addition of 1 M NaCl decreased the EC value of all the samples, with the lowest being A_2 and R_2 (33.5 and 30.8, respectively) as compared to control (46.3). A_1 and R_1 also had decreased EC levels in the presence of 1 M NaCl, the values being 38.0 and 45.0, respectively. The acidic butanol-treated flour had an EC of 32.5 in water and 25.3 in 1 M NaCl, which is lower than the control values.

DISCUSSION

Difference in nitrogen solubility profiles of control and heat-treated proteins could arise due to (1) denaturation of the protein, (2) surface charge variation as a result of protein–protein interaction and aggregation at elevated temperatures, and (3) masking of charged amino groups such as the ε-amino group of lysine due to either complexation with carbohydrates/reducing sugars or free CGA present in the microenvironment of the protein (Lapanje, 1978). The effect of NaCl on charge shielding of protein molecules with subsequent preferential binding of chloride ions with various protein fractions could be responsible for the increase in protein solubility in this electrolyte (Schwenke et al., 1978; Prakash, 1986; Prakash and Narasinga Rao, 1986). NaCl can bring about charge difference on the protein, leading to changes in solubility and thereby possibly reflecting the differential solubility of the various protein fractions with different isoelectric regions and also the preferential binding of chloride ions

(Prakash, 1986; Prakash and Narasinga Rao, 1986). The exposed surface charge of the protein which is charge shielded at lower pH values and the alkali peptization at higher alkaline pH are also predominantly responsible for the differences in the solubility (Prakash and Narasinga Rao, 1986; Prakash, 1986).

Dry heat can facilitate protein–protein interaction in the presence of low moisture and denature the protein to a large extent, resulting in a decrease in solubility (Cherry et al., 1975; Kinsella, 1979). Such heat denaturation of protein can decrease the solubility of the macromolecule in aqueous solvents (Kinsella, 1979; Prakash and Narasinga Rao, 1986).

The water absorption capacity of the heat-treated flours shows an increase depending on the extent and nature of heat treatment. The minor differences could be due to several factors, such as amino acid composition, protein conformation (size and shape), surface topography, surface charge and polarity, ionic concentration, variation in ionic species (anion or cation), pH, and temperature (Lewin, 1974; Kinsella et al., 1985). The increase in WAC of A_1, when compared to that of R_1, indicates the role played by moisture during heating. This could be due to the increase in water activity, which concomitantly increases the water associated with the protein. Severe heating results in an increased proportion of low molecular weight proteins in A_2 and R_2 (earlier papers), which could increase WAC as the proteins have a high percentage of charged amino acids, especially glutamic acid.

The increase in FAC of the dry heat-treated samples could be due to binding of the lipid to the proteins through the hydrophobic nonpolar amino acid side chains and the exposure of buried hydrophobic amino acids also as a result of denaturation (Kinsella, 1976). The decrease in FAC of the wet-heated samples could be due to aggregation of the proteins in these systems as evidenced from the results on physicochemical studies (Venktesh and Prakash, 1992, unpublished results). The moderate increase in FAC of A_2, compared to A_1, could be due to partial exposure due to denaturation of previously buried apolar amino acids that are not involved in binding as a result of aggregate formation.

The foaming properties imply that upon heat treatment the protein occupies a relatively larger surface area with hydrophobic amino acids being exposed to the bulk solvent, resulting in destabilized capillary pressure required for coalescence. A hierarchial decrease in the foam stability of the control followed by R_2, R_1, A_1, and A_2 in water was observed. However, in 1 M NaCl the value also decreases progressively with heat treatment, and a sharp decrease is found especially with the autoclaved samples.

Dissociated proteins have more capacity to foam and will also be stable as compared to the native protein molecule, where all the subunits are still together. The coalescing of the bubbles reduces the interfacial tension and stabilizes the foam by minimization of repulsion forces and limiting the drainage of the capillary water layer to a large extent as a result of protein denaturation.

Similar findings of various heat-treated proteins having different EA and ES values with a positive correlation between ES value and solubility of the protein have been reported. Increases in EA and ES values of all heat-treated flours in the presence of 1 M NaCl may be due to the increased solubility of the proteins in this solvent and the reduction of Coulombic interactions between neighboring droplets (Mita et al., 1978; McWatters and Holmes, 1979a; Waniska et al., 1981).

It is evident from the data that heat does not affect the EC values of the samples profoundly. A marginal decrease occurs in samples that had been exposed to high pressures, temperature, and solvent. One molar NaCl causes a decrease in the EC value in all of the samples.

The nature of hydrophobic groups which are exposed to the surface may largely determine emulsification properties of proteins and may effect a balance between net charge on the protein and the hydrophobicity. Several workers have reported positive correlations between protein solubility and emulsion capacity and emulsion stability of the protein (Yasumatsu et al., 1972; Volkert and Klein, 1979). Although denaturation decreased emulsification capacity, it might, on the other hand, increase its emulsification activity due to increased hydrophobicity, as observed in the case A_2 and R_2 (Tanford, 1970; Smith et al., 1973; McWatters and Cherry, 1975; Wang and Kinsella, 1976; McWatters and Holmes, 1979a,b; Aoki et al., 1980). Many studies are available for several proteins indicating a positive correlation between emulsifying activity and surface hydrophobicity (Shimizu et al., 1985; Kato et al., 1983; Howell and Lawrie, 1985).

Caution should be exercised in the interpretation of the results since defatted sunflower flour contains about 50–55% protein along with 30–35% carbohydrate, which is comprised of fiber, sugars, some starch, and other materials in the fraction. This could play an important role in protein–carbohydrate interactions, which could affect the functional properties of the flour.

The data clearly indicate that structural alteration in the protein molecule adversely affects the functional properties of the protein to a large extent. An understanding of the variation in functional properties as a result of heat treatment would help in better utilization of these proteins in specified end uses. This would also help in deeper understanding of the role of individual treatments on the seed proteins along with other constituents present in the matrix.

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