The objective of investigation was to study the influence of water activity on physicochemical properties (PCP) of defatted groundnut (*Arachis hypogea*), sunflower (*Helianthus annus*), rice bran (*Oryza sativa*) and soybean (*Glycine max*). Moisture free samples equilibrated at relative humidity (RH) levels from 22 – 84% were used for determination of PCP. Bulk density of samples decreased with increasing RH levels for sunflower, rice bran and soybean. Water absorption and emulsion activity of groundnut and sunflower increased with RH levels. However, an opposite trend was seen for rice bran and soybean. Fat absorption of all samples increased with increasing RH. Protein solubility of groundnut and sunflower was very high at RH of 84% in alkaline pH range. Protein solubility of rice bran was not affected by RH, whereas for soy flour it decreased with increasing RH. It can be concluded that water activity influenced the PCP of oilseed flour to a significant extent.

Keywords: bulk density, water absorption, fat absorption, emulsification, nitrogen solubility

Introduction

For plant proteins to be useful and have potential food applications, it is desirable that they possess several characteristics referred to as physicochemical or functional properties, apart from providing essential amino acids to fulfill nutritional needs (Wang and Kinsella, 1976). Oilseeds are very important component of agriculture, especially in tropical countries as they provide easily available and highly nutritious human and animal food. Oilseeds are rich sources of fats and protein and after extraction of oil the residual protein rich meal exhibits certain physicochemical properties which influence their functionality. These are used in product formulations and can affect the quality of end product. Some, such as protein concentrates especially from soybeans can directly function as substitute for meat or fish protein in diet lacking this component thus fulfilling the requirement of dietary nitrogen (Weiss, 1983).

In many high protein processed food products, proteins function as the basic fundamental components and are responsible for determining the textural, sensory and nutritional properties. Food products can have proteins from multiple sources each with different structural, physical, chemical and functional properties and sensitivity to heat and other treatments. To facilitate investigation into these specific properties of protein and also to appreciate their role in food systems, these were grouped together and defined as ‘functional properties’ by Kinsella (1976).

The sensory attributes of foods with high protein content can be controlled by appropriate processing and this has been facilitated by extensive study of factors that affect the behavior of proteins in various food systems. This has also offered a large variety of protein ingredients to the food industry, predominantly vegetable protein concentrates and isolates of diversified, controlled functionality and nutritional value (Sikorski, 1985).

In majority of foods water is the most abundant component and the macromolecules such as protein and carbohydrates are generally in intimate contact with water. The water molecules present in the environment and the water-mediated hydrogen bonds in the interior of some molecules contribute to the native confirmation of the proteins. Any changes in the confirmation of the molecules or micelles mediated by extrinsic factors, which also act on the water structures, are reflected in interaction of the proteins and water, leading to changes in solubility, water holding capacity, dehydration of
dried protein foods and swelling (Sikorski, 2001).

Water activity is defined as the water which is available for microbial, enzymatic or chemical activity that determines the shelf-life of a food, it is also known as the relative water pressure (Fellows, 2010).

Water activity tremendously influences the storage stability of foods. Many foods are capable of absorbing water if exposed to an environment of high relative humidity. This in turn can affect their functional properties. Since protein rich flours many a times are by- products of industry and are stored for sometime before they are used in other food formulation, the storage environment can affect their physicochemical properties thus influencing their functional behavior. Hence, the present study was undertaken with an objective to study the effect of water activity on functional properties of selected oilseed flours.

Materials and Methods
Materials
The study design involved determination of water activity of selected protein flours at different relative humidity. The flour equilibrated at different moisture levels were further used for analysis of physicochemical (PC) properties. Four commonly used oilseed flours selected for the study, namely, groundnut (Arachis hypogaea), sunflower (Helianthus annuus), rice bran (Oryza sativa) and defatted soybean (Glycine max) were obtained from local market. Groundnuts, sunflower seeds and rice bran were defatted by solvent extraction, milled and stored at ambient laboratory conditions till use. Refined sunflower oil was also purchased from local market. All the Chemicals used for the study were from SD Fine Chemicals Co. and Qualigens Ltd, Mumbai, India. Glass distilled water was used for the entire study. All analysis were carried out in triplicate.

Methods
Water sorption Moisture sorption isotherm of four oil seed flours were determined at room temperature (25°C) using the principle of water activity as suggested by Labuza et al. (1985). Different salts used for the study representing different water activity were as follows, potassium acetate (22%), magnesium chloride (33%), magnesium nitrate (54%), sodium nitrate (64%), ammonium sulfate (84%) and potassium nitrate (94%). The samples were made moisture free by drying them in oven for 2 days at 40°C till attainment of constant weight. A weighed amount of moisture free sample was placed in desiccator previously equilibrated with saturated salt solutions and moisture uptake was recorded every 24 h till seven days. All the flours were used for determination of PC properties from eighth day onwards. A sample kept at natural RH at room temperature served as control for all samples. This was used to see the difference from samples equilibrated at known RH levels.

Moisture The AOAC (2003) method was used for estimation of moisture in all samples.

Protein Protein content of flour and soluble protein was analyzed by Kjeldhal method and the protein content was obtained by multiplying the nitrogen value with 6.25 (Raghuramulu et al., 2003).

Determination of functional properties
Bulk density Bulk densities (BD) of all the samples were determined by the method of Wang and Kinsella (1976). A 3.0 g sample of the finely powdered (60 mesh) flour was placed in a 25 ml graduated cylinder and packed gently by tapping the cylinder on a rubber sheet until a constant volume was obtained. The procedure was repeated three times with different sample and the average value was taken. The bulk density was expressed as g ml⁻¹ of sample.

Water absorption capacity The water absorption capacities (WAC) of the samples were determined by the centrifuge technique described by Janicki and Walczak (1954). A 1.0 g sample was weighed into a calibrated graduated glass centrifuge tube. A 5.0 ml glass double- distilled water was added gently down the side and mixed with a thin glass rod. Any particles adhering to the glass rod were carefully washed with 2.0 ml of glass double distilled water into the same tube. The slurry was centrifuged at 3000 rpm for 25 min at 27°C. The volume of water above the sedimented sample in the tube was read and deducted from total water added and expressed as water retained ml/100 g.

Fat absorption capacity Fat absorption capacity (FAC) was determined by the method of Sosulski et al. (1976). To 1.0 g of sample 5.0 ml of refined sunflower oil was added, mixed thoroughly, weighed and kept aside for 30 min with gentle stirring with a glass rod every 5 min. The unabsorbed oil was determined by centrifugation of the slurry at 5000 x g at 27°C for 30 min. The complete removal of oil was achieved by draining the tube by keeping it at 45° angle for 1 h. The amount of oil retained was calculated by measurement of the difference in the weight of the sample before and after equilibration with oil. The fat absorption capacity was expressed as oil absorbed ml/100 g.

Emulsification activity and Emulsion stability The emulsifying activity (EA) was determined according to the method of Yasumatsu et al. (1972) by measuring the volume of the emulsified layer in relation to the total height of the contents after centrifugation at low speed. To 700 mg of protein concentrate was added 10 ml of distilled water and blended for 30 sec at 10,000 rpm. 10 ml of refined groundnut oil was added to the slurry and blended at higher speed of 12,000 rpm for 1 min. The emulsion thus formed was poured

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into a graduated centrifuge tube and centrifuged at low speed of 1200 rpm for 5 min. The EA was calculated by the equation.

Emulsion activity: $\frac{\text{Height of the emulsified layer after centrifugation}}{\text{Height of the total contents in the centrifuge tube}}$

The EA was expressed as percentage. For determining emulsion stability (ES) the emulsions prepared as described above were heated at 80°C in a water bath for 30 min and centrifuged again at 1200 rpm for 5 min. ES was also calculated using the above equation.

Protein solubility The soluble nitrogen contents of oilseeds as a function of pH were determined by extraction of the protein at different pH values and subsequent determination of nitrogen in the extracts. The samples equilibrated for moisture uptake at different RH were used. To 1.0 g of flour 10 ml of glass double-distilled water was added. The pH of the suspension was adjusted to the desired value by using 1.0 M HCl or 1.0 M NaOH. A precalibrated digital pH meter was used for pH adjustment and measurement. The suspensions were shaken in a water bath shaker at 27°C for 1 h. The slurry was centrifuged at 6000 rpm for 20 min at 27°C. Nitrogen was estimated in the supernatant by Kjeldahl method and expressed as percent protein solubilised in relation to total protein (AOAC, 1984).

Statistical analysis The data were presented as mean and standard deviation for all values. Correlation coefficient was computed to determine the association between water sorption and functional properties using statistical software SPSS version 10.0 for Windows.

Results and Discussion

The defatted flours of soybean, groundnut, sunflower and rice bran were analyzed for their moisture and protein contents (%) and the results were as follows, 4.6 ± 0.11 and 63.2 ± 0.40; 8.9 ± 0.9 and 54.7 ± 0.51; 7.5 ± 0.13 and 50.2 ± 0.37; and 10.2 ± 0.00 and 14.7 ± 0.19 respectively. The protein content of rice bran have been reported to be 55 and 56% respectively. After seven days soy flour absorbed 28.0 and 35.0% moisture at 84 and 94 RH.

These data indicate that at low RH of 22 and 33%, all the oilseed flours were very stable and did not absorb much water but on increasing the RH to 84 and 94%, they were not stable at high humidity environment as they absorb high content of water. A high water ingress in oilseeds flours at high humidity dictates the need for proper packaging material during storage. The samples stored at 94% RH developed mold growth after one week of storage; hence they were unfit for further use. For this reason they were not used for the determination of functional properties.

Since all samples exhibited varying levels of water uptake at different RH, showing a trend of higher absorption at higher RH, these may also have a bearing on functional properties. These were further used for determining functional properties with different moisture levels.

Martins and Netto (2006) stated that soy protein isolate stored at RH of 19, 33 and 74% after reaching to equilibrium exhibited 5.4, 6.7 and 14.3% moisture uptake.

Bulk density Data regarding functional properties of oilseed flours at different RH are compiled in Table 1. The BD of control samples of groundnut, sunflower, defatted rice bran and soy flour exhibited values of 0.40, 0.38, 0.60 and 0.60 g ml$^{-1}$ respectively. In case of groundnuts, we observed a marginal increase in BD with increasing RH, but in other 3 samples, BD decreased with increasing RH. The extent of decrease was lesser in sunflower seed flour from 0.38-0.33 g ml$^{-1}$ but was much higher in rice bran and sunflower. This was also obtained only at RH of 64 and 84% indicating that since samples had more water, the density was reduced. In
Fig. 1. Moisture uptake pattern of defatted oilseed flours at different relative humidity (%) over seven days.
Other words water occupied the space. This showed a very high negative correlation. BD of many protein rich flour and concentrates has been reported by different workers. Puyed and Prakash (2006) reported that the BD for two varieties of defatted soy flour was in the range 0.57 – 0.78 g/ml and that of peanut flour was 0.57 g/ml. Heat treatment did not affect the BD of peanut flour since moisture free samples were used but showed a slight insignificant increase in soy flour. Untreated, acid washed, heat stabilized and parboiled rice bran were freeze, cabinet and roller dried and exhibited BD in the range of 0.30 – 0.57, 0.63 – 0.88 and 0.60 – 0.66 g/ml respectively (Prakash and Ramanatham, 1995). Silva et al.(2003) reported BD of sesame and soy protein concentrate to be 0.42 and 0.41 g/ml respectively.

Water absorption capacity WAC of the control samples was lesser for sunflower and groundnut (31.8 and 37.6%) and higher for rice bran and soy flour (53.6 and 55.4%). Water holding capacity of defatted peanut flour as reported by Haiwen et al. (2009) was 2.3 g/g of the flour. In our study WAC of groundnut did not seem to be influenced by water activity, as it ranged from 33.1 – 34.0%. In sunflower seed flour again an increase was observed which was higher than what was seen in groundnut. From a sample stored at RH of 22, the difference was 30.0% higher at RH of 84%. WAC was positively correlated with water sorption and RH. However, in rice bran and soy, WAC decreased with increasing RH demonstrating negative correlation. These data can be correlated to water uptake of samples at different RH. The water uptake

<table>
<thead>
<tr>
<th>Oilseed</th>
<th>Control</th>
<th>Relative Humidity (%)</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>22</td>
<td>33</td>
</tr>
<tr>
<td><strong>Bulk density (g ml⁻¹)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundnut</td>
<td>0.40 ± 0.01</td>
<td>0.42 ± 0.00</td>
<td>0.43 ± 0.04</td>
</tr>
<tr>
<td>Sunflower</td>
<td>0.38 ± 0.00</td>
<td>0.38 ± 0.04</td>
<td>0.38 ± 0.03</td>
</tr>
<tr>
<td>Rice bran</td>
<td>0.60 ± 0.01</td>
<td>0.69 ± 0.02</td>
<td>0.68 ± 0.03</td>
</tr>
<tr>
<td>Soy bean</td>
<td>0.60 ± 0.01</td>
<td>0.62 ± 0.00</td>
<td>0.61 ± 0.01</td>
</tr>
<tr>
<td><strong>Water absorption capacity (mL/100 g)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundnut</td>
<td>37.6 ± 1.2</td>
<td>33.1 ± 0.67</td>
<td>33.5 ± 0.42</td>
</tr>
<tr>
<td>Sunflower</td>
<td>31.8 ± 2.1</td>
<td>28.5 ± 1.83</td>
<td>29.2 ± 0.42</td>
</tr>
<tr>
<td>Rice bran</td>
<td>53.6 ± 1.5</td>
<td>55.3 ± 2.33</td>
<td>54.1 ± 0.35</td>
</tr>
<tr>
<td>Soy bean</td>
<td>55.4 ± 0.14</td>
<td>47.2 ± 0.35</td>
<td>45.1 ± 0.14</td>
</tr>
<tr>
<td><strong>Fat absorption capacity (mL/100 g)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundnut</td>
<td>56.8 ± 1.41</td>
<td>55.5 ± 1.06</td>
<td>56.0 ± 0.71</td>
</tr>
<tr>
<td>Sunflower</td>
<td>61.6 ± 0.49</td>
<td>58.1 ± 0.64</td>
<td>58.5 ± 0.35</td>
</tr>
<tr>
<td>Rice bran</td>
<td>46.8 ± 0.99</td>
<td>37.9 ± 0.19</td>
<td>46.7 ± 0.20</td>
</tr>
<tr>
<td>Soybean</td>
<td>38.9 ± 0.85</td>
<td>40.6 ± 0.71</td>
<td>42.6 ± 0.49</td>
</tr>
<tr>
<td><strong>Emulsion activity / stability (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundnut</td>
<td>34.5 ± 2.14</td>
<td>24.5 ± 3.52</td>
<td>24.5 ± 3.53</td>
</tr>
<tr>
<td>Sunflower</td>
<td>48.5 ± 2.12</td>
<td>19.0 ± 1.41</td>
<td>27.0 ± 0.00</td>
</tr>
<tr>
<td>Rice bran</td>
<td>22.5 ± 0.71</td>
<td>37.5 ± 0.35</td>
<td>27.5 ± 0.71</td>
</tr>
<tr>
<td>Soybean</td>
<td>24.5 ± 3.54</td>
<td>36.0 ± 8.49</td>
<td>33.9 ± 2.12</td>
</tr>
</tbody>
</table>
of groundnut was very low till RH of 64%. In comparison, sunflower showed a higher uptake at similar RH. Rice bran absorbed a high amount hence exhibited lower WAC. In soy flour, the decrease was to lesser extent as again it had a very low uptake.

The water absorption characteristics of protein flours and concentrates have been reported by many workers. Kabiruulla and Wills (1982) studied the hydration characteristics of sunflower flour and protein isolates obtained from aqueous, alkali and salt solutions and reported that flour had the highest rate of water absorption. Water soluble sunflower protein isolate absorbed the highest amount of moisture at all levels of RH. However at the RH range 23 – 68%, the alkali and the salt soluble sunflower protein isolate adsorbed similar amount of moisture. Studies on the level of bound and free water in defatted sunflower concentrate showed that the limit of water was highest in sunflower (29.2 g/100 g) and water soluble sunflower protein isolate (28.3 g/100 g). A general trend showed increased water binding with increased protein content, particularly in the range of 60 – 90% protein. Increase in water binding with protein content is not linear, suggesting that additional factors other than protein content contribute to water binding (Hansen, 1978). Pea protein isolate containing 85 – 86% protein exhibited lower water hydration capacity (2.80 – 3.21 g water/g) than soy concentrate and isolate (5.52 and 5.85 g water/g respectively) (Naczk et al., 1986). For rice bran proteins, the uptake of water (240 ml/100 g) was higher by roller dried samples from untreated and acid stabilized bran and compared well with freeze dried samples. This was attributed to gelatinization of starch during roller drying as the samples had considerable amount of carbohydrates (Prakash et al., 1995). Kaur and Singh (2005) found the WAC of different chick pea flours to be between 1.33 – 1.47 g/g. Sosulski et al. (1987) studied water hydration capacity of dehulled cow pea seed flour stored at 64 and 79% RH for 6 months and found it to be 94 and 89 ml/100 g respectively in comparison to control sample with a value of 90 ml. The values were much higher for wet processed protein concentrates with 204, 174 and 188 ml/100 g of the sample, and were attributed to higher protein content. Sesame protein concentrate showed a much lower WAC at 175 ml/100 g than soy protein concentrate at 215 ml/100 g, which again could be due to higher level of protein present in the soy protein concentrate (Silva et al., 2003). The rice bran samples studied for effect of ultrasonic assisted alkali extraction of protein did not show any significant differences in WAC against conventional method (25.1 and 21.4 ml/100 g) respectively.

Fat absorption capacity The FAC of flours is important as it improves the mouth feel and retains the flavor (Kinsella, 1976). Fat absorption also imparts anti-staling characteristics to products. FAC for groundnut flour and sunflower seed flour were not influenced by different RH levels, only slight variation could be observed on treating samples in different RH range. The range of changes from control to 84% RH for groundnut and sunflower were 56.8 – 57.1 and 61.6 – 62.3% respectively. A high correlation was seen for sunflower sample (correlation coefficient - 0.980). Haiwen et al. (2009) reported the oil binding capacity of defatted peanut flour to be 2.6 ml/g of sample. FAC of rice bran and defatted soy flour slightly increased when RH increased in our study. As presented in Table 1, these changes ranged from 37.9 – 53.1% for rice bran and 40.6 – 46.9% for defatted soy flour. Fat absorption was not influenced by the RH for these two samples as extent of association was small. It has been said that the surface properties of protein play an important role in FAC. Processing conditions, degree of modification and method of drying also affect the fat absorption properties (Nagmani and Prakash, 1997). Paredes-Lopez et al. (1991) reported that the FAC of chickpea protein isolates with 84.8 – 87.8% protein was higher for micelle protein (2 ml/g protein) than for iso-electric protein (1.7 ml/g protein) and was comparable to soy isolate (1.9 ml/g protein). Kaur and Singh (2005) stated that the FAC of desi chick pea flour ranged from 1.05 – 1.71 g/g. The higher value in comparison with the present study is due to higher protein concentration. Silva et al. (2003) reported that the oil absorption capacity of sesame protein concentrate and soy protein concentrate were 325 and 220 ml/100g of the sample. According to Chittapalo and Noonhorm (2009) oil absorption of defatted rice bran protein concentrate extracted using the ultra sonication method was higher than the conventional method which was 15.2 and 13.1 ml/100g respectively.

Emulsification activity and stability The EA and ES values were similar for all oilseed flours (Table 1). EA is defined as the ability of the flour to emulsify the oil. The EA and ES for groundnut and sunflower seed flour showed an increase with increasing RH levels. The control could emulsify 34.5 and 48.5% of oil whereas in all other level of RH it had lower values with the range being 24.5 – 32.5 and 19 – 41% for the respective samples. A high correlation was seen for sunflower. Rice bran and soy flour showed a different pattern, EA decreased with increasing RH from 37.5 – 20.0% for rice bran and 36.0 – 23.0% for soy flour. It might be noted that in these two samples, WAC also showed a decrease with increasing RH, whereas groundnut and sunflower exhibited an increase. Kaur and Singh (2005) estimated ES of different chick pea flours in the range of 76.6% – 82.1%. Flours from kabuli chickpea cultivar showed significantly lower EA (58.2%) than did the desi chickpea (59.6 – 68.8%).
ference in total protein composition as well as components other than protein (like carbohydrates) may contribute substantially to the emulsification property of protein containing product like legumes (McWatters and Cherry, 1977). Khalid et al. (2003) studied effect of pH on emulsion capacity of sesame total protein isolate and reported that it had minimum capacity (70 ml oil/g protein) at pH 5.0 with an increase on either side of pH 5.0. Sathe et al. (1982) stated that emulsion capacity of lupin seed flour and protein concentrate was 55.1 and 89.9 g/g respectively. Lin et al. (2006) reported emulsion capacity of soy flour as 95.1%.

**Protein solubility** The application of high protein materials in food industry depends to a great extent on their functionality. To estimate protein functionality, nitrogen solubility profile estimates over a range of pH are used as a guide because this property usually correlates with other properties such as emulsification and foaming capacity. The protein solubility profile of samples stored at different RH are compiled in Fig. 2. The control samples exhibited a typical bell-shaped curve of solubility as is generally seen for oilseed flours. Groundnut flour at low pH of 2.0 showed high solubility of 35.6% which reduced as the pH increased with solubility of 4.8% at pH 5.0, known as isoelectric pH for groundnut proteins. The solubility was high at alkaline pH of 9.0 and 11.0 with the value ranging from 38.5 – 41.9%. The groundnut flour stored at different RH had almost similar profiles as that of control. The sample stored at 84% RH showed very high solubility in the pH range from 9.0 – 11.0 with the value being 74.5 – 80.7%. Kim et al. (1992) studied peanut nitrogen solubility and reported peanut protein fractions in water and 0.2 M NaCl exhibited a U-shaped pattern. Minimum solubility of peanut protein was at the isoelectric point (pH 4.0-5.0) and more than 95% protein was solubilised at pH below 2.5 and above 7.0.

The control sample of defatted sunflower seed had the least solubility compared to all other samples (Fig. 2). At pH 2.0 only 10.5% protein could be solubilised from the control sample and it further decreased to 5.5% at pH 6.0. In the alkaline range, though solubility improved, the maximum value seen was only 21.5% at pH 11.0. Samples at different RH levels had higher initial solubility levels at acidic pH in comparison to control. The pH 6.0 was identified as isoelectric pH for samples stored at different RH levels. In alkaline range samples stored at RH of 22, 33, 54 and 64% comparatively had higher protein solubility than control and values ranged from 37.9 – 42.3%. It was observed that at alkaline pH of 11.0 and RH of 84, both groundnut and sunflower seed flour had very high solubility with values of 80.7 and 81.0%. It indicated that high water imbibition assisted to raise protein solubility especially at alkaline pH, as the samples were pre-hydrated.

The protein solubility profile of rice bran flour samples indicate that almost all samples at different RH levels had a similar profile and water activity did not influence protein solubility to a major extent. The control samples had a solubility of 14.0% at pH 2.0 which decreased gradually to reach solubility of 3.6% at pH 6.0. The values at pH 7.0 and 8.0 were lower than acidic pH of 2.0 but pH 9.0 demonstrated a sudden increase in solubility with a value being 24.6%, this further increased to 25.9% at pH 11.0. Knorr (1982) studied the effect of dehydration methods on the functionality of rice bran protein concentrates prepared by the alkali extraction and heat coagulation of protein at pH 5.0 and reported that samples dried by 3 different methods were similar in functionality with high solubility of 20 – 25% at pH 10.0. Wang et al. (1999) reported that nitrogen solubility of rice bran protein isolate in water was minimum at pH 4.0 and increased gradually below pH 4.0 and above pH 6.0. Maximum solubility was observed at pH 10.0.

Defatted soy flour control had a higher solubility in comparison with all other oilseed and soy flours stored at different RH levels. At pH 2.0 the solubility was 74.5% and decreased to 34.8% at pH 5.0. In alkaline range it exhibited very high solubility starting from 70.0% at pH 8.0 to 87.0% at pH 11.0. Martins and Netto (2006) also reported a decrease in protein solubility by about 60% with increase in water activity from 23.3% to 9.6%. According to Saio et al. (1982), among the oilseed flours and protein isolates suspended in water at pH's ranging from 2.5 – 9.0, soy and peanut showed higher solubility. Effect of time, temperature and pH on solubility behavior of rice bran proteins was studied by Champagne et al. (1985). An increase in protein solubility was observed when pH of slurry increased from 4 – 11. The solubility also increased with decreasing pH below 4.0. It followed the typical bell shaped solubility behavior of protein from various vegetable sources. The above results indicate that with increasing RH, solubility decreases, hence soy protein is best used in dry form.

Lawal et al. (2007) and Zhang et al. (2007) studied nitrogen solubility of Bambarra groundnut and soy protein respectively and their observation were in same trend. According to Khalid et al. (2003) the minimum nitrogen solubility of sesame protein isolate was 12% between pH 4.0 and 6.0. On either side of pH 4.0 and 6.0, there was a sharp increase in the solubility of total protein isolate. At pH 3.0 and 1.0 about 90 and 72% of the nitrogen was soluble. According to Hainwen et al. (2009) the nitrogen solubility of peanut protein products were higher in the pH range of 2.0-3.0 and reduced in the pH of 4.0-5.0 following which steady increases were observed for the protein solubility as the pH increased.
Fig. 2. Protein solubility of defatted oilseed flours as a function of pH at different relative humidity.
Adebowale and Lawal (2003) studied nitrogen solubility of *mucuna* bean protein concentrate and reported that solubility decreased with increase in pH until it reached minimum solubility of 19.4% at isoelectric point (pH 4.0), followed by increase in solubility with increasing pH values after the isoelectric point. The protein solubility of sesame protein concentrate and soy protein concentrate were lowest at pH 5.0 and highest at pH 10.0 and typical curve shape was obtained as in the present study (Silva *et al.*, 2003). Protein solubility of quinoa flour was 14% at start of storage study and significant decrease of solubility was found during storage time (Abugoch *et al.*, 2009). Chittapalo and Noomhorm (2009) reported that the nitrogen solubility index profile for defatted rice bran concentrate extracted with conventional and ultrasonic method showed lowest value at pH 4.0 – 6.0 but below and above this pH, nitrogen solubility index increased. At pH 2.0 they showed 40 and 30% solubility respectively. The highest solubility observed at pH 12.0 were 95 and 85% for extracts prepared through conventional and ultrasonication methods respectively. Aluko and Monu (2003) studied protein solubility of quinoa seed protein concentrate against its protein hydrolysates and pH of 5.0 showed least solubility. There was a very significant difference between protein concentrate and hydrolysates in nitrogen solubility as at pH 3.0, it was 25 and 95% and at pH 8.0, it was around 70 and 80% respectively.

To conclude, water activity influenced the physicochemical properties of oilseed flour to a significant extent, the effect was dependent on the type of oilseed and varied between samples. It shows that the storage environment of protein flours is very important as change in relative humidity can cause changes in the functional behavior of oilseeds, which in turn will affect the quality of end products to which they are added.

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