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Surface tension of *Phaseolus vulgaris* and *coccineus* proteins and effect of polysaccharides on their foaming properties

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Abstract

The surface tension of protein isolates from common bean (*Phaseolus vulgaris* L.) and scarlet runner bean (*Phaseolus coccineus* L.), prepared by isoelectric precipitation and ultrafiltration was evaluated, with respect to protein concentration (0.001–0.1% w/v) and pH (pH 4.5, 5.5, 7.0 and 8.0). Surface tension was most reduced, and with a higher rate of reduction at higher protein concentration and at pH 8.0. Foams (1, 2% w/v protein), at the same pH values, with and without the addition of polysaccharides, were studied. The proteins' foaming behaviour was related to their adsorption behaviour. Arabic gum, locust bean gum (0.1% and 0.25% w/v), xanthan gum and a xanthan/locust bean gum mixture (0.1% w/v) had a positive effect on foam creation. All polysaccharides increased foam stability, probably due to the viscosity increase and to the creation of a network, which prevents the air droplets from coalescence. Isolates from *P. coccineus* and isolates obtained by ultrafiltration seemed to exhibit better foaming properties.

Keywords: *Phaseolus*; Surface tension; Foaming properties; Arabic gum; Locust bean gum; Xanthan gum

1. Introduction

Legume seeds play an important role in the world's food supply, as they are one of the most important sources of protein, carbohydrates and dietary fibre in human nutrition. Common bean (*Phaseolus vulgaris* L.) and scarlet runner bean (*Phaseolus coccineus* L.) are two very important sub species, known for a thousand years, and are cultivated mainly in America, but also in Europe, Asia and Africa (Sathe, 2002; Smart, 1990).

Phaseolus beans contain 20–30% protein on a dry weight basis. They contain vitamins and have a balanced amino acid composition. They are low in sulfur-containing amino acids, which is common among legumes (Chang & Satterlee, 1979; Augustin & Klein, 1992; Gueguen & Cerletti, 1994; Sathe, Iyer, & Salunkhe, 1981; Tako, 1991).

The storage proteins of *Phaseolus* beans are vicilin, legumin and phytohaemagglutin. Vicilin, which represents 50% of the total protein content, is a 7S globulin and is often referred to as phaseolin. Legumin is an 11–12S globulin comprised of acid and basic subunits and usually sediments with vicilin as a single component. (Gepts & Bliss, 1986; Kohnhorst, Smith, Uebersax, & Bennink, 1991; Kohnhorst, Uebersax, & Zabik, 1990; Sathe, 2002).

Foams are a very significant category of food colloids (Dickinson, 1992). Proteins, either alone or in collaboration with other surface active components, are adsorbed at the interface of newly formed gas bubbles, creating a layer around them. The basic requirements for a protein to be a good foaming agent are the ability to: (a) adsorb rapidly at the air–water interface during bubbling, (b) undergo rapid conformational change and rearrangement at the interface, (c) form a cohesive viscoelastic film *via* intermolecular interactions. The first two criteria are essential for good foaming ability, whereas the third is important for the stability of the foam (Damodaran, 1994; Dickinson & McClements, 1996).

The protein adsorbed layer protects the foam from destabilization. Some of the destabilization mechanisms

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are coalescence, Ostwald ripening, evaporation and liquid drainage, due to gravity or capillary pressure (Dickinson & Stainsby, 1988; Zayas, 1997). The above mechanisms mainly occur, due to the rupture of the interfacial film.

The stability of a foam is influenced by its film thickness and its mechanical properties (the film needs to be cohesive, viscous, elastic, continuous and air-impermeable), protein–protein interactions and finally environmental factors (ionic strength and temperature). Increased bulk liquid viscosity results in strong foams, as a result of significant cohesive forces between protein molecules. The stability of the foam is also greatly determined by the properties of the protein used, like its solubility, structure and flexibility and, of course, its concentration. (Damodaran, 2005; Dickinson, 1999; Zayas, 1997). Protein molecules' configuration and conformational flexibility influence foam stability, since more flexible molecules tend to unfold and undergo more structural changes during adsorption, leading to the development of strong interfacial hydrophobic interactions and associated displacement of vicinal water from the surface. The distance of the pH from the isoelectric region of the protein affects the protein molecule unfolding, the inter- and intramolecular interactions and the surface pressure. In this way, the pH determines to a great extent the properties of the interfacial film created and, hence, the foam stability.

Polysaccharides are often added as stabilizing and thickening agents, in order to alter the rheological characteristics or stabilize the colloid systems (Dickinson, 2003; Dickinson & Stainsby, 1988). Gum arabic is a natural exudate of the trees of *Acacia senegal* and is widely used in the beverage industry. The gum has been shown to be highly heterogeneous, it is a complex proteoglycan acid salt (mainly Ca, K, Mg and Na) of high molecular weight (average 4×10^5). It is composed of D-galactose, L-arabinose, L-rhamnose, as well as D-glucuronic acid and its 4-*O*-methyl ether (Karamallah, 2000). Three main components have been recognized. A fraction (90% of total gum) with very little protein content (~1%) and another fraction (1% of total gum) with a high protein content (20–50%), do not adsorb at the interface. Finally, a fraction (10% of total gum) with a protein content of ~10%, which does adsorb at the interface, is responsible for the emulsifying properties of the gum (Islam, Phillips, Sljivo, Snowden, & Williams, 1997; Randall, Phillips, & Williams, 1989; Ray, Bird, Iacobucci, Clark, & Jr, 1995). Though different models have been proposed, the most accepted model for the emulsifying fraction of the arabic gum is the "wattle

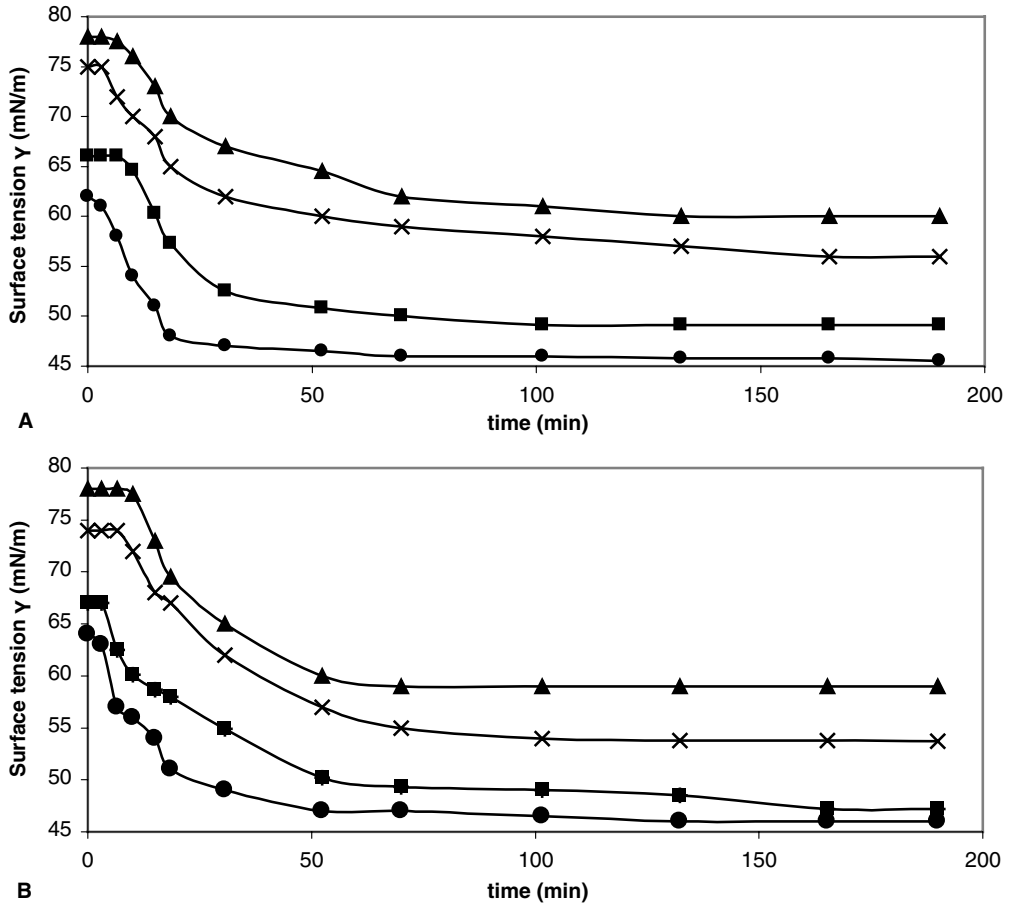

Fig. 1. Surface tension, as a function of time, of V isolate solutions at pH 8.0 at different concentrations, ● 0.1% w/v, ■ 0.01% w/v, × 0.005% w/v, ▲ 0.001% w/v (A): VpI & (B): VUF.

blossom'' (Osman, Menzies, Williams, Phillips, & Baldwin, 1993).

Galactomannan, also known as locust bean gum, is a seed-reserve polysaccharide with a (1 → 4)-β-D-mannan backbone substituted with (1 → 6)-β-D-galactosyl residues. The galactose substituents are clustered mainly in doublets approximately randomly spaced, the hairy regions, interspersed by longer regions of unsubstituted mannan backbone, the smooth regions (McCleary, Clark, Dea, & Rees, 1985; McCleary, Dea, Windust, & Cooke, 1984). Galactomannans from different sources exhibit differences in their structure, mainly in the distribution of D-galactosyl units along the mannan chain. These differences seem to modify interaction properties (Bresolin et al., 1997; Lazaridou, Biliaderis, & Izydorczyk, 2000; Schorsch, Garnier, & Doublier, 1997).

Xanthan, a non-adsorbing biopolymer, has been widely used because of its excellent viscosity and dispersion. It is an exocellular polysaccharide of *Xanthomonas campestris* and its primary structure consists of a (1 → 4)-β-D-glucopyranosyl backbone substituted at *O*-3 on every second residue with a charged trisaccharide side chain consisting of two mannosyl units with a glucuronic acid residue situated between them. The terminal mannosyl unit may be substituted at *O*-4 and *O*-6 by a pyruvic acid acetal moiety. On the internal mannosyl; residue an *O*-acetyl group may be present (Jansson, Kenne, & Lindberg, 1975; Severian, 1998). Xanthan at high concentration promotes stabilization, by conferring a very high apparent viscosity on the continuous phase and/or generating a strong network in the continuous phase (Braudo, Plashichina, & Schwenke, 2001; Carp, Bartholomai, Relkin, & Pilosof, 2001; Carp, Bartholomai, & Pilosof, 1999; Dickinson, Golding, & Povey, 1997; Dickinson, Goller, & Wedlock, 1995; Papalamprou, Makri, Kiosseoglou, & Doxastakis, 2005).

Synergistic properties of xanthan and locust bean gum are widely known and depend on the association of unsubstituted regions of the galactomannan with the backbone of the xanthan helix (Cairns, Miles, & Morris, 1986; Cheetham & Mashiba, 1990; Dea et al., 1977; Lopes, Andrade, Milas, & Rinaudo, 1992). Different models have been proposed but they all refer to the existence of specific junction zones, through which the formation of a network is achieved (Cairns et al., 1986; Cairns, Miles, Morris, & Brownsey, 1987; Dea et al., 1977; Morris, 1992). Furthermore, a decrease in the synergistic effect has been observed with an increase in the galactose substitution of the galactomannan molecule (Dea & Morrison, 1975; Dea, Clark, & McCleary, 1986; McCleary et al., 1984; McCleary, Amado, Waibel, & Neukom, 1981). Another model (Lundin & Hermansson,

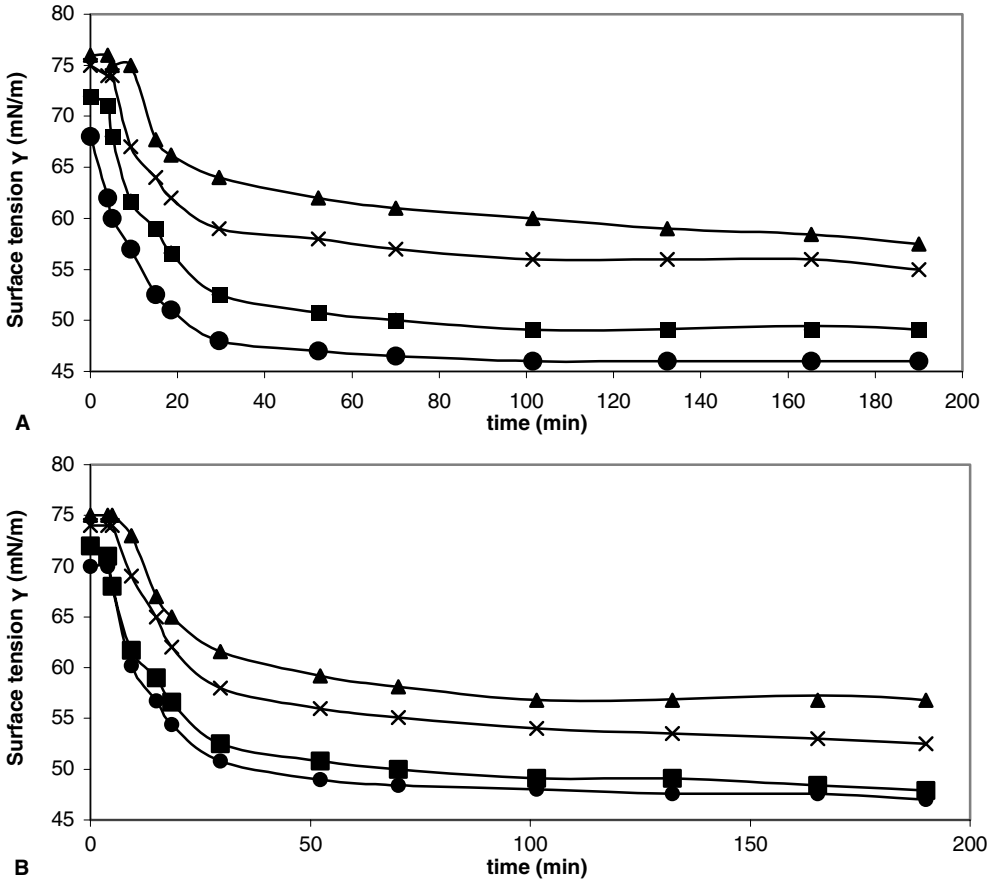

Fig. 2. Surface tension, as a function of time, of Coc isolate solutions at pH 8.0 at different concentrations, ● 0.1% w/v, ■ 0.01% w/v, × 0.005% w/v, ▲ 0.001% w/v (A): CocpI & (B): CocUF.

1995) suggested that the network would be formed by xanthan superstrands, interconnected by the galactomannan itself absorbed or linked onto the surface of the xanthan superstrands, the length of which depended on the mannose/galactose ratio. Other models have also been proposed. However, the interactions between galactomannan and xanthan are not fully known (Mannion et al., 1992; Tako, 1991; Zhan, Ridout, Browsey, & Morris, 1993).

The present study examines the surface tension of solutions of *Phaseolus* proteins (from two different cultivars and prepared with different methods) at different protein concentrations and pH values, with respect to time. Moreover, it examines the effect of the addition of gum arabic, locust bean gum, xanthan gum, and finally, a mixture of xanthan gum and locust bean gum, to the properties of foams prepared with bean proteins from two different cultivars (common bean and scarlet runner bean), extracted either by isoelectric precipitation or ultrafiltration.

2. Materials and methods

2.1. Materials

Common bean (*P. vulgaris* L.) (V) and scarlet runner bean (*P. coccineus* L.) (Coc) seeds are of Protected Geographical Indication and were provided by "AGROKA" (Kastoria Greece). Commercially available refined corn oil was obtained from the local market and used without further treatment. Commercial arabic gum (GA), locust bean gum (LBG) and xanthan gum (XG) were provided by Sigma Chemical Co. Cst. Louis, Mol. All the pH adjustments were made with 1 N NaOH and 1 N HCl solutions. NaCl was bought from Riedel-de-Haën and was of analytical grade.

2.2. Methods

2.2.1. Preparation of seed protein isolates

Protein isolates were prepared from *P. vulgaris* and *P. coccineus* by the isoelectric precipitation method described elsewhere (Alamanou & Doxastakis, 1995, 1997). The pH of the alkaline extraction was 8.5 and the precipitation of the protein was performed at pH 4.5. All centrifugations described were at 4000 rpm for 20 min. These isolates will be referred to as VpI and CocpI, respectively. Protein isolates were also prepared by an ultrafiltration method. According to this method, seeds were ground in a kitchen type mill (Braun, Germany) and the resulting flour (~100 mesh) was dispersed in distilled water (1/10). The pH was increased to 8.5 and the suspension was stirred

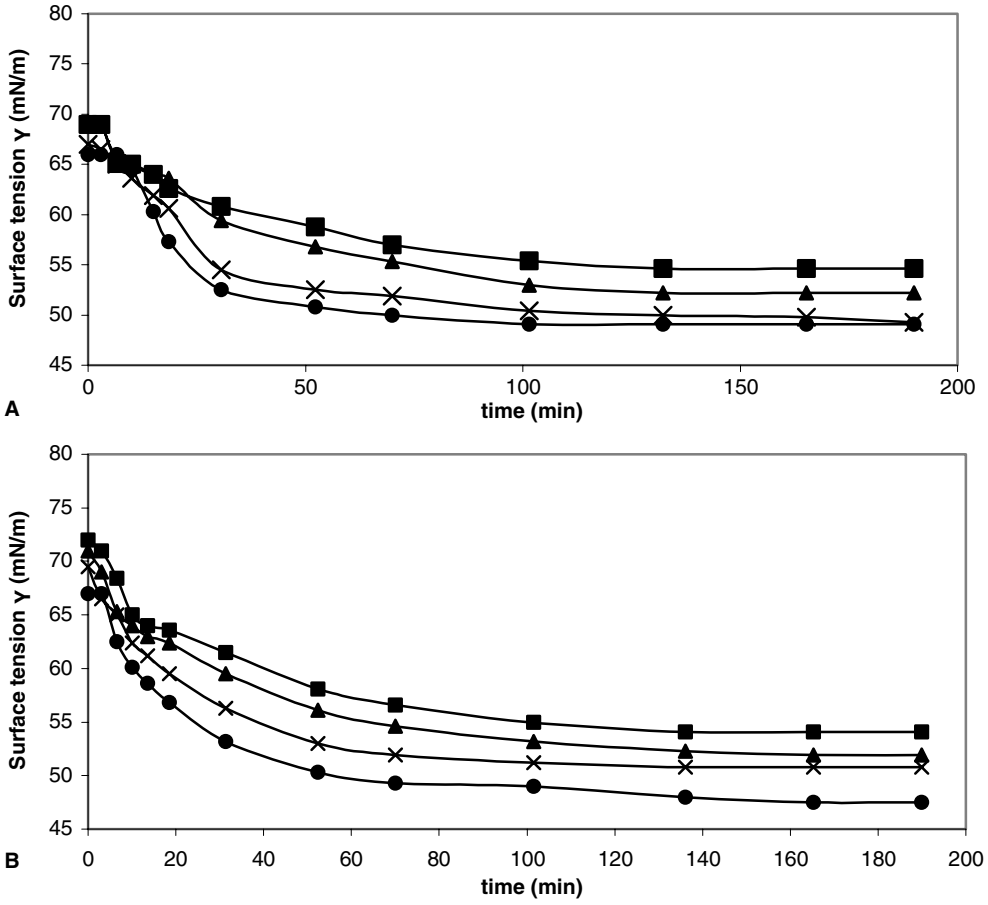

Fig. 3. Surface tension, as a function of time, of V isolate solutions at concentration 0.01% w/v, at different pH values ● pH 8.0, × pH 7.0, ▲ pH 5.5, ■ pH 4.5 (A): VpI & (B): VUF.

for 40 min, and then centrifuged at 4000 rpm. The residue was collected and treated as before with distilled water(1/5). The two supernatants were collected, combined and their pH value was adjusted to 7.0. This solution was then forced through an ultrafiltration device (Millipore Pellicon XL), which was operating at 5 bar pressure, with a PLCGC 10K ultrafiltration membrane (50 cm^2 with a molecular of cut-off of 5000 Da). Protein solution pH was readjusted to 7.0 and then lyophilized. These isolates will be referred to as VUF and CocUF, respectively. The protein content of all isolates was determined by the Kjeldahl method ($N \times 5.7$) (Pearson, 1976). The protein contents of VpI and VUF were 72.31% and 66.0%, respectively, and of CocpI and CocUF were 69.20% and 68.70%, respectively.

2.2.2. Surface tension determination

Adsorption behaviour of protein isolates was evaluated by measurements of surface tension development at the air/water interface with time. Measurements were made using the ring method with a Kruss tensiometer (Kruss GmbH-Hamburg Model K8, Germany). Protein solutions at concentrations 0.1%, 0.01%, 0.005% and 0.001% w/v were prepared from both *Phaseolus* cultivars and with both methods of extraction (VpI, VUF, CocpI, CocUF) at pH 8.0. The surface pressure was also measured for solutions of all the above protein isolates at 0.001% w/v at pH values 8.0, 7.0, 5.5, 4.5. All experiments were carried out at 25 °C.

2.2.3. Preparation and evaluation of foams

Protein solutions (100ml) of 1% or 2% w/v protein concentration were prepared and adjusted to the desired pH (8.0, 7.0, 5.5, 4.5). In some cases 0.1% or 0.25% w/v of GA, LBG, XG or XG-LBG mixture (1:1), were added to the protein solutions and homogenized with a mechanical stirrer. The solution was then whipped at maximum speed (1000 rev min^{-1}) for 5 min in a Braun, Germany. Finally, foams were carefully transferred to a 1 l glass measuring cylinder. The initial foam volume, along with the foam volume and liquid drainage after 30 min, were measured.

Foaming capacity was evaluated by relative overrun (Hammershoj & Qvist, 2001)

$$\text{Relative overrun} = V_0/V_i$$

where V_i is the initial liquid volume and V_0 is the foam volume at 0 min.

Foam stability was studied by comparing the foam after 30 min with the initial foam (0 min) (Hammershoj & Qvist, 2001)

$$\text{Foam Stability} = V_{30}/V_0$$

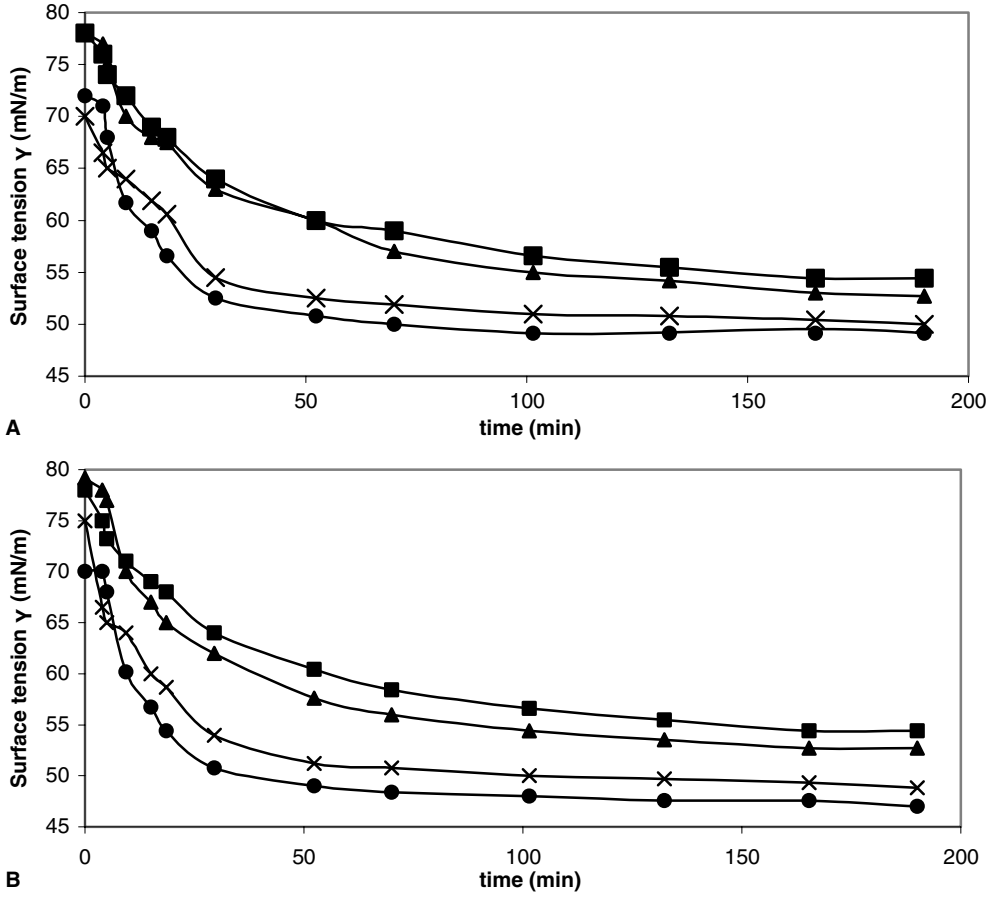

Fig. 4. Surface tension, as a function of time, of Coc isolate solutions at concentration 0.01% w/v, at different pH values ● pH 8.0, × pH 7.0, ▲ pH 5.5, ■ pH 4.5 (A): CocpI & (B): CocUF.

where V_0 is the initial foam volume and V_{30} is the foam volume at 30 min.

Liquid drainage was calculated as the drainage from the foam in a 30 min period (Hammershoj & Qvist, 2001)

$$\text{Liquid drainage} = 1 - (V_i - V_{L30})/(V_i - V_{L0})$$

where V_i is the initial liquid volume, V_{L30} is the volume of liquid at 30 min and V_{L0} is the volume of liquid at 0 min.

2.2.4. Statistical analysis

Each experiment was repeated at least three times and the data was analyzed using one-way analysis of variance. The level of confidence was 95%. Significant differences between means were identified by LSD procedure.

3. Results

Fig. 1 presents the changes in surface tension at the air/water interface of the VpI and VUF isolates at different concentrations (0.001–0.1% w/v). It can be seen that surface tension changes more when the protein concentration is higher. For the higher concentrations studied, the decrease in surface tension with time is more pronounced both initially as well as for the steady state finally achieved. This applies also for the Coc isolates (Fig. 2). The differences between the concentrations studied are better exhibited for the isolates prepared with isoelectric precipitation for both *Phaseolus* cultivars, since for concentrations 0.005% and 0.001% w/v the surface

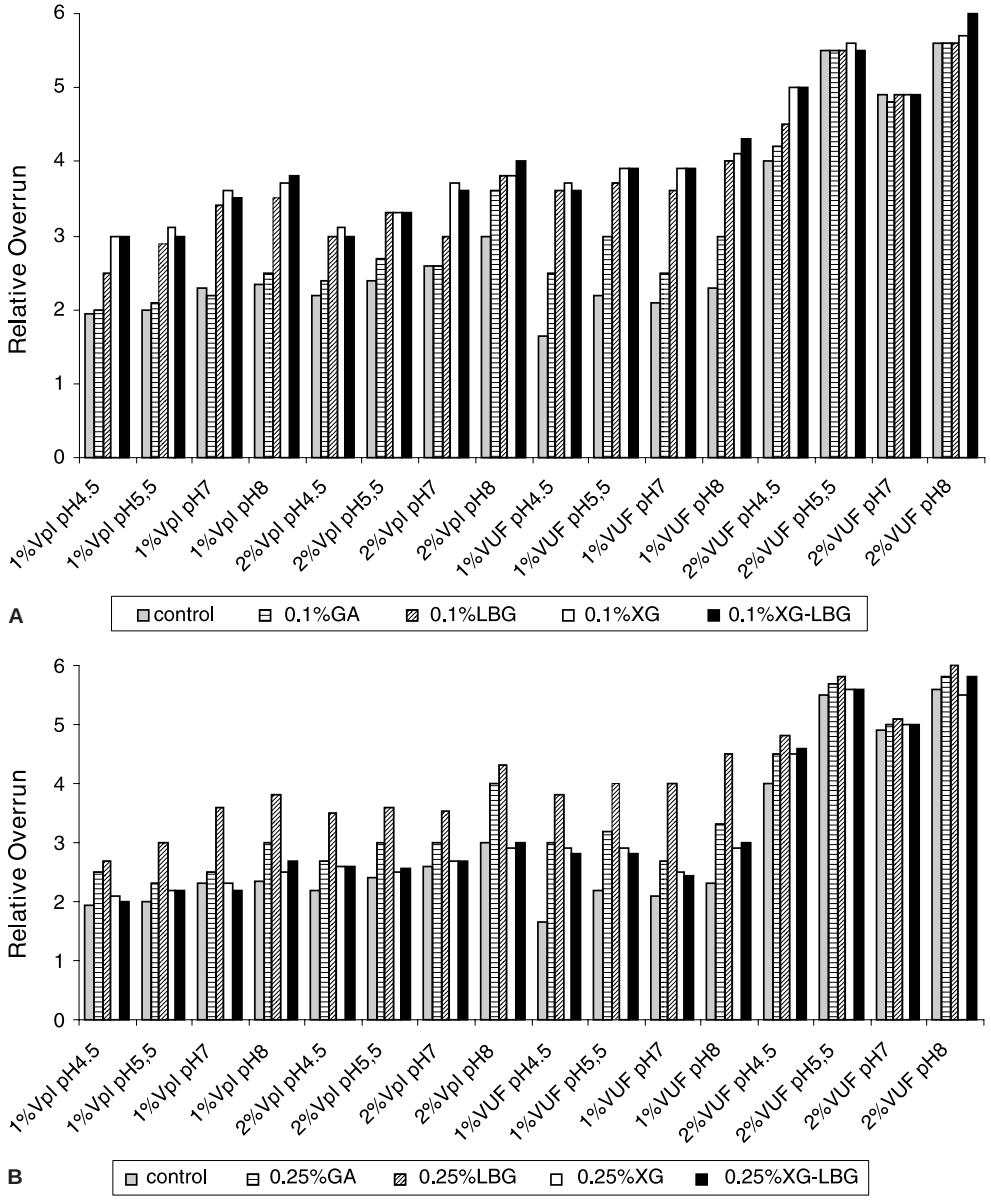

Fig. 5. Relative overrun of foams prepared with 1% or 2% w/v VpI or VUF at pH 4.5, 5.5, 7.0 or 8.0 without (control) or with GA, LBG, XG or XG-LBG mixture: (A) 0.1% w/v polysaccharide concentration and (B) 0.25% w/v polysaccharide concentration.

reduction is less high than for the concentrations 0.1% and 0.01% w/v. This is even more pronounced for the V isolates than the Coc. The values for surface tension are in accordance with values reported before for many different legume proteins (Dilollo, Alli, Biliaderis, & Barthakur, 1993; Krause, Mothes, & Schwenke, 1996; Tsaliki, Kechagia, & Doxastakis, 2002; Palazolo, Sorgentini, & Wagner, 2004; Papalamprou et al., 2005). Furthermore, the observation that at higher protein concentrations the surface activity is increased is in agreement with previous data (Damodaran & Paraf, 1997; Patino, Sanchez, Ortiz, Nino, & Anon, 2004; Sanchez, Nino, Ortiz, Anon, & Patino, 2004) and is due to the fact that the protein amount available for the coverage of the air/water interface and the building of a rigid interfacial film is insufficient.

When measuring the surface tension a lag period was observed which is typical of the adsorption of globular proteins from solutions, being more pronounced at lower protein concentrations. This induction period is often attributed to the flexibility of molecules and their susceptibility to conformational changes. It also correlates with the time required to attain a small monolayer coverage. From a kinetic point, the surface tension is determined after this induction period by a different process. The protein diffuses from the solution to the subsurface, then it unfolds and adsorbs at the interface and finally the adsorbed protein segments rearrange at the interface forming a monolayer (at protein concentrations lower than that of the plateau) (Ortiz, Sanchez, Nino, Anon, & Patino, 2003; Patino et al., 2004; Razumovsvky & Damodaran, 1999; Sanchez et al., 2004; Wagner & Guegen, 1995).

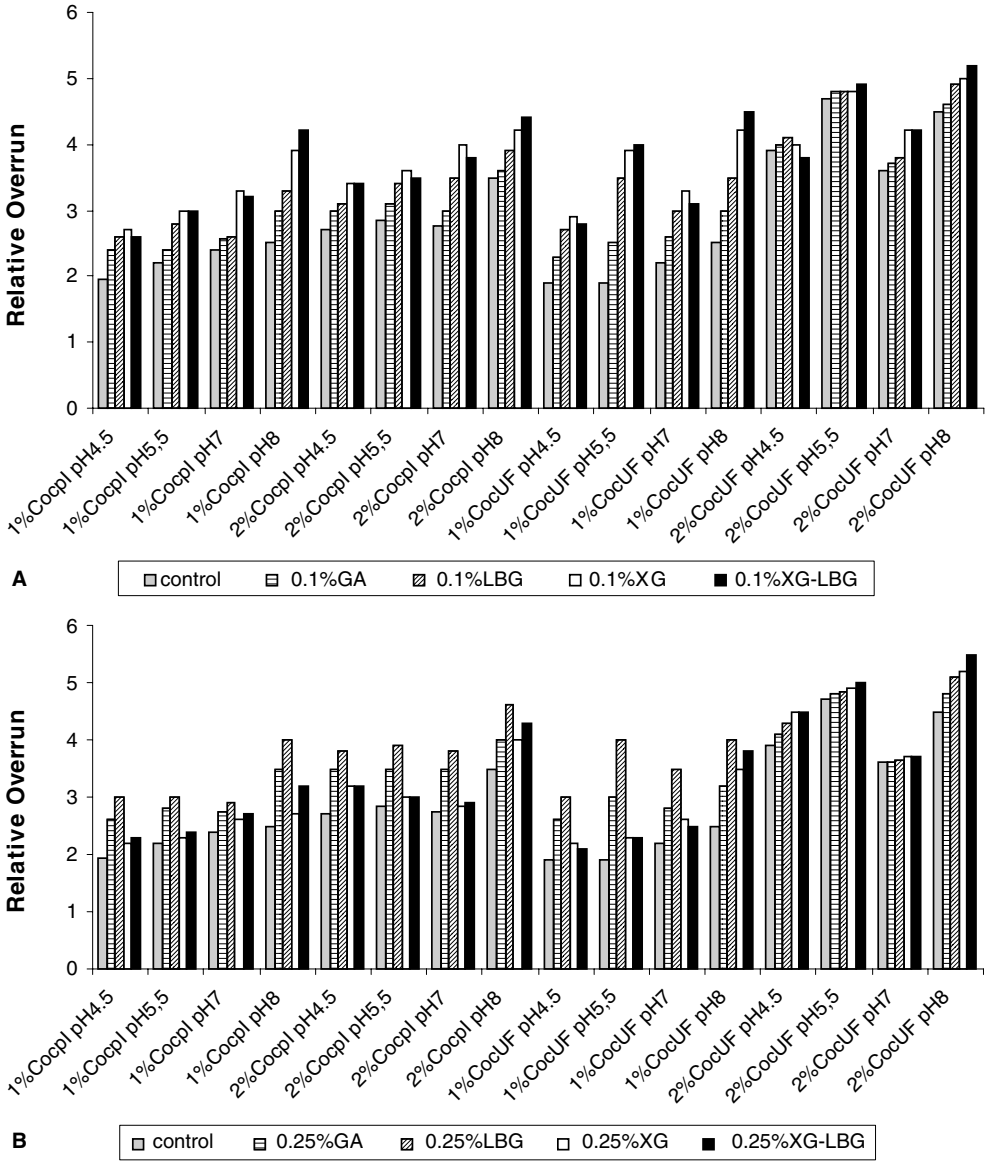

Fig. 6. Relative overrun of foams prepared with 1% or 2% w/v CocpI or CocUF at pH 4.5, 5.5, 7.0 or 8.0 without (control) or with GA, LBG, XG or XG-LBG mixture: (A) 0.1% w/v polysaccharide concentration and (B) 0.25% w/v polysaccharide concentration.

The dependence of the surface pressure on pH is shown in Figs. 3 and 4 for the V and Coc isolates, respectively. For both *Phaseolus* cultivars and for both method of protein extraction at pH 4.5 and 5.5 the reduction in surface tension values is smaller compared to pHs 7.0 and 8.0, since at the higher pH values the rate of decrease is higher and the plateau values are lower. Moreover, for the UF isolates the initial surface value is higher than that of the pI isolates, so the total decrease could be considered even higher. For the Coc isolates, at pH 7.0 and 8.0, the values at the plateau are lower for the UF isolates (and lower than the respective VUF values), while at pH 4.5 and 5.5 the final surface tension value achieved is almost the same, irrespective of the method for protein extraction followed. For V, all UF isolates exhibit lower final surface tension values, with pH 8.0 differences being the most pronounced whereas pH 7.0 differences were relatively small.

The protein adsorption behaviour, with respect to the pH of the aqueous phase, should be interpreted with respect to the protein molecule changes, as an effect of the pH value. At a pH near the isoelectric point of the protein, the molecule obtains a more compact form. This makes it more difficult for the molecule to move and adsorb at the interface. In general, disordered, small and flexible proteins reduce the surface tension earlier and faster than ordered, rigid and larger proteins, while, the adsorption rate is mainly determined by molecular size and structure (Bos, Dunnewind, & van Vliet, 2003; Dickinson, 1999; Ortiz et al., 2003; Zayas, 1997).

The way proteins behave at the air/water interface is related to their foaming properties (Langevin, 2000; Bos et al., 2003; Damodaran, 1994; Damodaran & Paraf, 1997; Martin, Bos, & vanVliet, 2002; Zayas, 1997). Moreover, polysaccharides are often added as stabilizing and

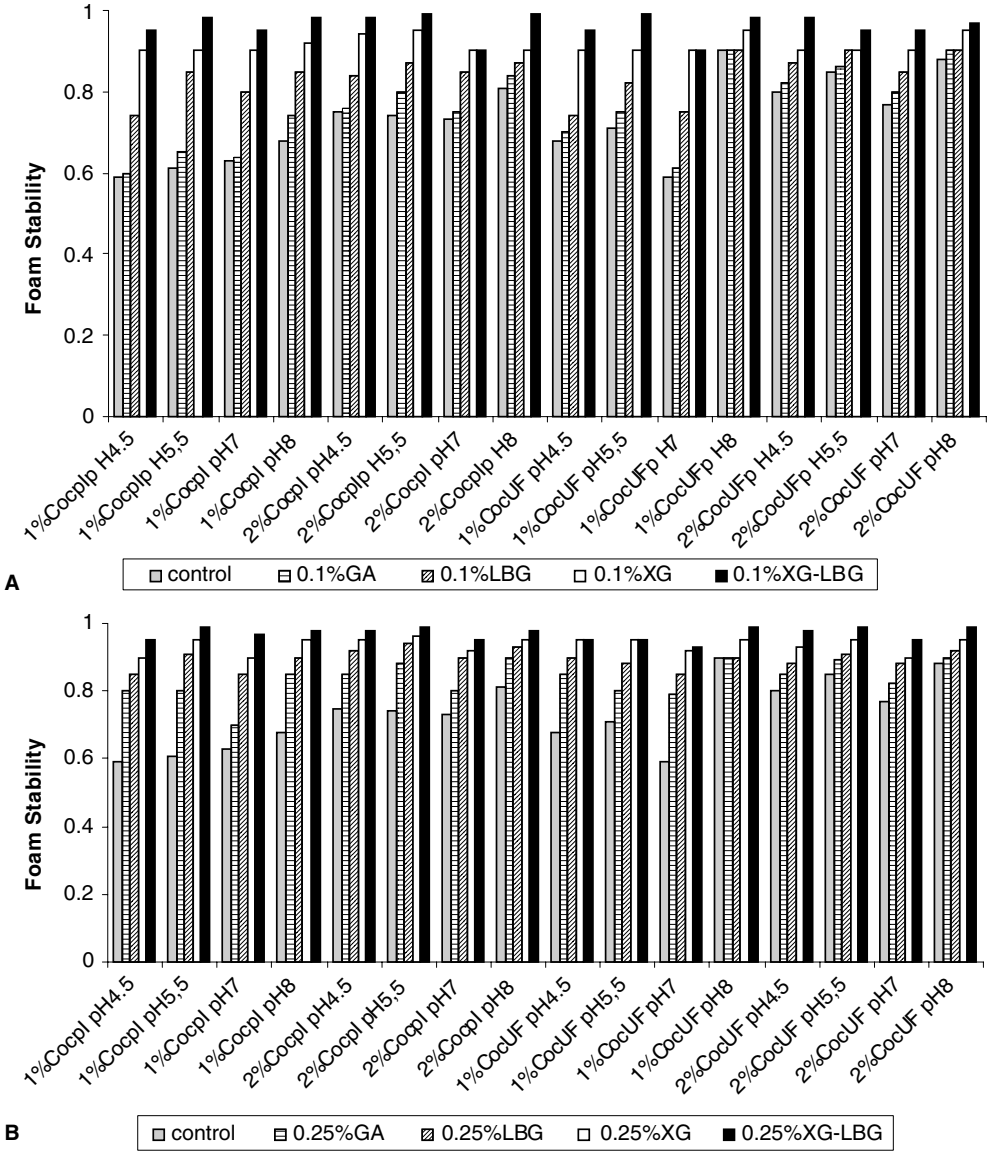

Fig. 7. Foam stability of foams prepared with 1% or 2% w/v CocpI or CocUF at pH 4.5, 5.5, 7.0 or 8.0 without (control) or with GA, LBG, XG or XG-LBG mixture: (A) 0.1% w/v polysaccharide concentration and (B) 0.25% w/v polysaccharide concentration.

thickening agents in colloid systems. Fig. 5 presents the relative overrun of foams prepared with 1% and 2% w/v VpI or VUF at pH 4.5, 5.5, 7.0 and 8.0, with the addition of 0.1% w/v (Fig. 5A) and 0.25% w/v (Fig. 5B) GA, LBG, XG and XG-LBG mixture. Relative overrun is enhanced by an increase in protein concentration, especially for UF isolates. Foam creation seems to be promoted at pH 8, irrespective of the method of protein extraction. The addition of 0.1% w/v GA and LBG cause an increase in relative overrun while addition of XG and XG-LBG cause a greater increase. When the polysaccharide concentration is raised, GA and LBG promote more foam creation than at the lower concentration, whereas XG and XG-LBG do not seem to promote the creation of foam. The UF isolates exhibit more differences between them with the addition of polysaccharides. The Coc, both pI and UF, isolates create more foam with increased protein concentration, which is promoted with the addition of 0.1% w/v polysaccharides (Fig. 6A). Moreover, the relative overrun is higher for all of the foams prepared at pH 8.0, irrespective of polysaccharide addition. When 0.25% w/v GA and LBG are added the relative overrun is improved, in contrast to 0.25% XG and XG-LBG addition, which does not promote foam, unlike at 0.1% w/v concentration. However, at pH 8.0 and to a lesser extent at pH 5.5 for 2% UF more foam is created.

Fig. 7 presents the foam stability of foams prepared with 1% and 2% w/v CocpI or CocUF at different pH values (4.5, 5.5, 7.0, 8.0), with the addition of 0.1% w/v and 0.25% w/v polysaccharides (Fig. 7A, B, respectively). The increase of protein concentration results in an increase in foam stability, which is more pronounced for the UF isolates. Furthermore, at pH 8.0 and to a lesser extent at pH 5.5, the stability of foam seems to be enhanced. The addition of 0.1% w/v GA and LBG enhanced foam stability, and the effect was greater for 0.1% w/v of XG and

Table 1
Liquid drainage of foams prepared with 1% or 2% w/v VpI or VUF isolates, at pH 4.5, 5.5, 7.0, 8.0 without or with the addition of 0.1% w/v GA, LBG, XG and XG-LBG

Liquid drainage								
pH	4.5	5.5	7.0	8.0	4.5	5.5	7.0	8.0
	PI							
	1% V				2% V			
Control	0.85	0.80	0.85	0.80	0.70	0.70	0.80	0.70
0.1 GA	0.84	0.77	0.82	0.76	0.66	0.68	0.77	0.65
0.1 LBG	0.80	0.72	0.77	0.70	0.64	0.65	0.74	0.62
0.25 GA	0.80	0.73	0.83	0.75	0.65	0.62	0.76	0.64
0.25 LBG	0.75	0.69	0.80	0.70	0.60	0.60	0.72	0.58
	UF							
Control	0.90	0.80	0.95	0.80	0.70	0.70	0.80	0.70
0.1 GA	0.87	0.77	0.90	0.75	0.68	0.61	0.76	0.65
0.1 LBG	0.83	0.72	0.84	0.70	0.62	0.58	0.74	0.62
0.25 GA	0.85	0.76	0.89	0.71	0.66	0.60	0.72	0.64
0.25 LBG	0.80	0.65	0.85	0.68	0.58	0.57	0.69	0.58

Table 2
Liquid drainage of foams prepared with 1% or 2% w/v CocpI or CocUF isolates, at pH 4.5, 5.5, 7.0, 8.0 without or with the addition of 0.1% w/v GA, LBG, XG, XG-LBG

Liquid drainage								
pH	4.5	5.5	7.0	8.0	4.5	5.5	7.0	8.0
	pI							
	1% Coc				2% Coc			
Control	0.85	0.80	0.80	0.75	0.69	0.70	0.80	0.78
0.1 GA	0.83	0.75	0.78	0.70	0.66	0.65	0.76	0.75
0.1 LBG	0.80	0.72	0.76	0.68	0.64	0.62	0.74	0.71
0.25 GA	0.82	0.74	0.78	0.69	0.65	0.64	0.76	0.72
0.25 LBG	0.77	0.70	0.75	0.62	0.61	0.68	0.73	0.65
	UF							
Control	0.85	0.85	0.90	0.80	0.60	0.60	0.80	0.77
0.1 GA	0.82	0.82	0.88	0.75	0.58	0.57	0.78	0.74
0.1 LBG	0.80	0.80	0.85	0.72	0.55	0.55	0.75	0.72
0.25 GA	0.80	0.81	0.84	0.73	0.56	0.55	0.77	0.73
0.25 LBG	0.75	0.75	0.81	0.70	0.58	0.50	0.72	0.65

XG-LBG. At higher polysaccharide concentrations, the foaming stability seems to be increased, but with GA and LBG the result is more pronounced compared to XG and LBG, for which the stability was similar to that observed at 0.1% w/v concentration. Similar behaviour is exhibited by the V isolates (data not shown).

Table 1 shows the liquid drainage of plain foams and foams prepared with VpI or VUF, with the addition of GA and LBG. When the protein concentration is high the drainage is reduced. The liquid drainage is also reduced with the addition of polysaccharides. Comparing GA and LBG, the latter has the larger effect and its effect is improved when its concentration is 0.25% w/v. The pH value and method of protein extraction influenced the foam created. At pH 8.0 and 5.5 for the UF isolates (especially for 2% w/v protein concentration) the drainage is reduced. Similar observations could be made for the Coc isolates (Table 2). Compared to V isolates the 2% w/v Coc UF seemed to result in less drainage. The liquid drainage for foams prepared with the addition of XG or XG-LBG mixture was greatly reduced (data not shown).

The foaming properties were better when the protein concentration is increased, due to the fact that the protein must be sufficient to cover the air bubble surface, create a rigid film around it, and so produce more foam (Britten & Lavoie, 1992; Sanchez & Patino, 2005; Sathe & Salunkhe, 1981; Satterlee, Bembers, & Kendrick, 1975). The above observations are in agreement with the results from the surface tension measurements. The pH alters the configuration of the protein molecules, consequently altering the capacity and stability of the foam created. At pH 8.0, foam creation is better for all foams studied, while foaming stability is enhanced at pH 8.0 and 5.5. At pH values far from their isoelectric point the molecules are in a less compact form, move to the interface and arrange themselves at the interface quickly, as has been observed from the surface tension measurements, promoting foam formation. Our results are in agreement with data reported by Satterlee et al. (1975). The increased foam stability at pH 5.5 could be attributed to the fact that the more compact structure that the protein molecule obtains at this pH leads to the creation of a more cohesive film around the air bubbles, which protects them from coalescence. The method of protein extraction influences the foaming properties (in quality and quantity), and the UF isolates have proved to be better foaming agents, especially at higher concentrations, where Coc isolates also dominate (Makri, Papalamprou, & Doxastakis, 2005; Fidantsi & Doxastakis, 2001; Tsaliki, Kechagia, & Doxastakis, 2002). This reveals that protein origin and its method of extraction are of great importance for the foam created.

Foaming ability and stability has proven to be beneficially affected by the addition of polysaccharides (Fidantsi & Doxastakis, 2001; Tsaliki et al., 2002). This positive effect is effect firstly attributed to the increase of viscosity of the aqueous phase and secondly to the creation of a network, which stabilizes the interfacial film (air–water). The differences between the polysaccharides studied are mainly due to their different contribution to the viscosity increase. It has been shown that these polysaccharides produce viscous solutions in the following order GA < LBG < XG (Yaseen, Herald, Aramouni, & Alavi, 2005). Furthermore, XG-LBG mixtures are known to exhibit a synergistic behaviour, resulting in highly viscous solutions, which probably explains the increase in relative overrun. However, the addition of 0.25% w/v XG or XG-LBG does not seem to help in the creation of foam. It seems that the greatly increased viscosity of the aqueous phase does not allow air to enter the system and create an acceptable foam. The stability of foams and the drainage were also affected in the same way. Due to the increased viscosity of the aqueous phase, the coalescence of the air bubbles was prevented and the liquid drainage was reduced.

4. Conclusions

The adsorption behaviour of *Phaseolus* bean protein isolates has been evaluated by surface tension measurements at the air/water interface. At higher protein concentrations and at pH far from the isoelectric point surface tension is reduced to a higher degree and at a higher rate. This is probably due to the fact that at high concentration the protein is sufficient to fully cover the interface and at higher pH obtains the flexibility and mobility to do so, building a rigid and viscoelastic protein film around the air droplet.

The foaming properties are relevant to the protein adsorption behaviour and have shown to be influenced by the protein concentration, the pH of the aqueous phase, as well as by the presence of polysaccharides. The addition of GA or LBG (0.1 and 0.25% w/v) enhances the creation of foam and its stability by increasing the continuous phase viscosity and by promoting a network, which protects the air droplets from coalescence. XG and XG-LBG have a similar effect on foam creation at 0.1% w/v, while at 0.25% w/v only the stability is increased, probably due to the great increase in viscosity, making it more difficult for air to enter the system during the preparation of the foam. Differences between the two *Phaseolus* cultivars and the method of protein extraction have been noticed and in particular Coc and UF isolates seem to promote foam formation and stability, especially at higher protein concentration.

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