Colloids and Surfaces A: Physicochem. Eng. Aspects 382 (2011) 74–80

Contents lists available at ScienceDirect

Colloids and Surfaces A: Physicochemical and Engineering Aspects

journal homepage: www.elsevier.com/locate/colsurfa

Foaming activity of lupin protein isolates in the absence of insoluble protein aggregates

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ARTICLE INFO

Article history:
Received 27 September 2010
Received in revised form
10 November 2010
Accepted 11 November 2010
Available online 19 November 2010

Keywords:
Lupin
Protein aggregates
Foam ability
Foam stability
Electrical conductivity

ABSTRACT

This study investigates the foaming properties of two lupin protein isolates (LPIs) extracted by ultrafiltration (albumin-rich fraction; LPTF) and isoelectric precipitation (globulin-rich fraction; LPTE), respectively. An earlier work on LPIs extracted by similar methods, Alamanou and Doxastakis [1], blamed the insoluble protein aggregates for the worse foamability and foam stability of the LPTE isolate compared to the LPTF isolate. Herein, the foaming properties of LPI are examined after removal of the insoluble fraction in order to appraise solely the effect of dissolved proteins. Foams are produced by whipping 1% w/v of LPIs aqueous solutions at pH 5.5 and 7, alone but also with addition of xanthan gum (0.05% and 0.1% w/v) and NaCl (0.1 M). Foaming ability and stability are assessed globally by volumetric measurements and locally by electrical conductance measurements taken non-intrusively at different heights along the foam. Both LPIs showed satisfactory foaming activity with electrical measurements depicting local drainage features that global volumetric measurements could not capture. It is found that LPTF yields better foamability than LPTE, exactly as it was shown earlier in the presence of aggregates. However, there is a discrepancy with that earlier work regarding foam stability since the two isolates perform comparably in the absence of aggregates. The discrepancy may be explained by considering that the larger size LPTE aggregates could have a stronger destabilizing effect than the smaller size LPTF aggregates. The role of pH, xanthan gum and NaCl in affecting the performance of the two LPIs is also discussed.

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1. Introduction

Lupin proteins have gained increasing commercial importance the last decades not only because of their nutritional quality but also due to their ability to be used as, or incorporated into, foods which will be readily consumed [2]. Lupin protein foaming performance depends on the composition and solubility of proteins which, in turn, depend on seed variety and on the method applied for isolating the proteins from the seed [3]. Globulins represent about 87% of the total proteins of lupin seed while albumins only 13% [4].

Recently, there has been focus on the effect of insoluble protein aggregates, such as those found in commercial protein concentrates, on interfacial and foam properties [5–7]. It was found that although interfacial properties may not be affected at all, aggregates in some cases have a positive effect whereas in others a negative effect on foam stability. It was argued that this might depend on the size of aggregates: large aggregates destabilize foams whereas small aggregates stabilize foams [8].

Electrical conductance methods have been extensively employed for both understanding the conductive properties of foams (e.g., [9,10]) and for the investigation of foaming properties (e.g., [11–13]). Working with soya protein wet foams, Karapantsios and Papara [14] reviewed the critical design and operational aspects of electrical conductance techniques in measuring foaming properties. Electrodes geometry/arrangement and electric current excitation frequency were shown to be the most important parameters affecting the sensitivity and accuracy of measurements. In addition, a small but clear effect of bubble size on electrical measurements was presented. In a subsequent study, Papara et al. [15] examined how the diameter, wettability and shape of the container walls affect the liquid profile along protein foams during drainage. To our knowledge, the above studies were the first on protein foams that elaborated on the proper reduction of electrical data to volumetric liquid fractions.

The aim of the present work is to investigate the foaming performance of two prototype lupin protein isolates produced in pilot scale [16]. The isolates were obtained by two different wet extraction methods, isoelectric precipitation and ultrafiltration, namely. The former is enriched in proteins of the globulin fraction whereas the latter of the albumin fraction. Although there is evidence of the functional performance of these isolates in salad dressing emulsions, meat products, bread dough, etc. [17–19], little is known

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doi:10.1016/j.colsurfa.2010.11.025

Table 1
Indicative chemical analysis of lupin protein isolates type E (LPTE) and type F (LPTF) (courtesy of the Fraunhofer Institute, IVV, Germany).

	LPTE	LPTF
Protein content (N% × 6.25)[a]	93%	92%
Fat content[a]	2%	0.8%
Ash[a]	4%	0.5%
Carbohydrates (by difference)	1%	6.7%

[a] Values based on dry mass.

about their foaming behavior [16]. Alamanou and Doxastakis [1] examined the foaming activity of lupin proteins isolated from *Lupinus. albus*, ssp. Graecus seeds by similar extraction methods. Their globulin-rich isolate, prepared by isoelectric precipitation, presented considerably lower foaming ability and foam stability than the other isolates. It was assumed that isoelectric precipitation has induced aggregation of proteins which depleted monomer concentration and as a result decreased the rate of lowering surface tension. The check of this hypothesis motivated our work: to examine the foaming performance of lupin protein isolates in the absence of insoluble aggregates. In addition, Alamanou and Doxastakis [1] did measurements only at pH 5.5, a value close to the isoelectric point of the protein, where protein solubility is low and protein molecules are less flexible and so are less capable of adsorbing at interfaces than at other pH values. Furthermore, these authors created foams by slow gas injection through a tube which is a method leading to relatively large bubbles with narrow size distribution, a situation not realistic from a technological point of view.

In this work, the foaming performance of the aforementioned prototype isolates are examined at pH 5.5 and 7, in the presence of xanthan gum and sodium chloride but having removed the insoluble protein aggregates from the aqueous solutions before foam production. Foams are created by intense whipping which is technologically more realistic than bubbling through a sparger (e.g. in terms of bubbles polydispersity). Measurements include the determination of (a) the local liquid fraction at different heights along the foam by a non-intrusive electrical conductance technique and (b) the global liquid fraction of the entire foam column computed from measurements of the drained liquid and the foam volume.

In the following sections, the foam preparation procedure is presented first followed by a description of the experimental setup, the measuring techniques and the data reduction procedure. A section comes next with experimental results and discussion on the underlying phenomena.

2. Experimental

2.1. Materials

Prototype in isolates type E and type F (henceforth designated as LPTE and LPTF, respectively) were kindly provided by the Fraunhofer Institute (IVV, Freising, Germany). LPTF was prepared from flaked de-oiled sweet (low alkaloid) lupin seeds by extraction of albumins with cold water at pH∼5, followed by ultrafiltration and spray-drying. LPTE was prepared from the remaining proteins, chiefly globulins, being extracted with water at pH∼8, and recovered from the extract by precipitation at pH 4.6 and, finally, spray-dried. Thus, LPTF is an albumin rich fraction whereas LPTE is a globulin-rich fraction. Analysis by SDS-PAGE revealed that both lupin isolates are contaminated by protein constituents of the other type [17]. The solubility of LPTE at pH 5.5 and 7 is ∼35% and ∼70% whereas the solubility of LPTF is ∼60% and ∼70%, respectively [18]. An indicative chemical analysis of the isolates can be found in Table 1. Despite the high protein concentration, both LPIs include appreciable amount of other constituents that may affect foaming activity e.g. fat, inorganic matter (ash), etc. Their role cannot be quantified at present.

Table 2
Characteristics of the employed LP solutions and their final values of pH and electrical conductivity at 25 °C.

LP solution	Additive	pH	Conductivity (mS/cm)
1.0%, w/v LPTE	–	5.5	0.60
1.0%, w/v LPTE	0.05%, w/v XG	5.5	0.65
1.0%, w/v LPTE	0.10%, w/v XG	5.5	0.69
1.0%, w/v LPTE	0.1 M NaCl	5.5	10.80
1.0%, w/v LPTE	–	7.0	0.74
1.0%, w/v LPTF	–	5.5	1.15
1.0%, w/v LPTF	0.05%, w/v XG	5.5	1.11
1.0%, w/v LPTF	0.10%, w/v XG	5.5	1.05
1.0%, w/v LPTF	0.1 M NaCl	5.5	11.20
1.0%, w/v LPTF	–	7.0	1.38

Xanthan gum (XG) purchased from SIGMA is used to stabilize the foams. XG solutions are naturally hydrophilic and, therefore, do not have a high tendency to adsorb at the air water interface. However, recent evidence supports an additional role for polysaccharides which may interact with proteins at the interface affecting the interfacial rheological properties of the system e.g. increase the dilatational viscosity [20,21].

2.2. Foams preparation

LPTE and LPTF solutions are prepared in 100 ml of de-ionized water or 0.1 M NaCl solution at 1% w/v by gentle mechanical stirring (IKA-Labortechnik RW 20.n, Germany) for 1 h. The natural pH of the solutions is 5.2. The pH value is adjusted to 5.5 or 7.0. The pH-adjusted protein solutions are left for 24 h at 4 °C. Then, the insoluble protein fraction is removed by centrifugation at 10,000 rpm for 25 min (ROTINA 35, HETTICH). The soluble fraction is used then to prepare the protein/polysaccharide solutions by gradually adding 0.05% or 0.1% (w/v) XG and stirring gently for 1.5 h. Finally, the pH and electrical conductivity are measured and the solutions are stored at 4 °C for additional 24 h. The characteristics of the prepared LPTE and LPTF solutions and their final values of pH and electrical conductivity are shown in Table 2.

It must be stressed that in most studies the value of the electrical conductivity of the protein solution is not mentioned. Our protein solutions are prepared with de-ionized water instead of buffer solutions (so widely employed by other authors to control the pH) because we noticed that the high salinity of buffer solutions had stronger effects in the foam behavior than the protein and the polysaccharide together. Others, too [22,23], have noticed such effects.

Foams are prepared by whipping air into 50 ml of the above solution using a Sunbeam Mixmaster mixer (Main st. supply, USA) for 5 min at 900 rpm. Part of the produced foams is immediately decanted to a Plexiglas cylindrical container up to its top and is allowed to drain freely. The temperature of the foams during the course of drainage is 24 ± 1 °C.

2.3. Experimental container and measurements

The experimental container is made of Plexiglas with 4.0 cm i.d. and 15.5 cm height. The container is furnished with four parallel stainless-steel ring electrodes mounted flush on its inner surface at 4, 5,7 and 10 cm, respectively, above its bottom. Electrodes are 3 mm wide. The container together with electrodes is presented in Fig. 1. Electrodes combined in pairs yield several conductance probes. Data are acquired from five electrode pairs (probes): AB, BC, CD, AD, and BD. However, in this study only data from the four probes shown in Table 3 are presented.

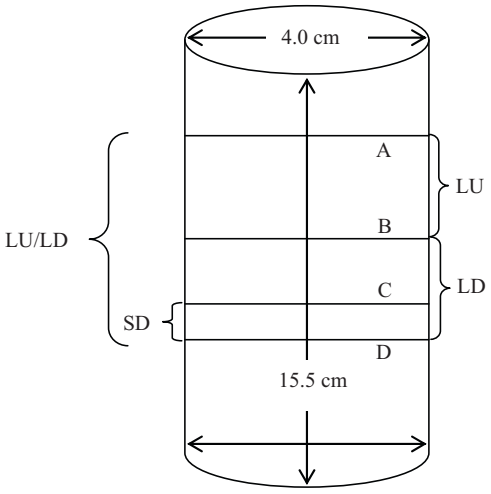

Fig. 1. Geometrical features of experimental container and ring electrodes A, B, C, D. In this study, only data from probes LU, LD, SD and LU/LD are used.

In all probes, the electrodes separation distance is large enough to average bubble size undulations, yet small enough to preserve the local character of measurements. Probes LU and LD provide average information from the entire cross-section of the container from the upper and lower part of the foams, respectively. On the contrary, the probe SD gives information from the lower part of the foams and chiefly from the region near the container wall [24].

Instantaneous electrical conductance values of the draining foam from the different probes are obtained by employing the technique of Karapantsios and Papara [14]. A few essential elements are repeated here. An a.c. carrier voltage of 0.3 V (peak-to-peak) is applied across each electrode pair at a frequency of 25 kHz in order to suppress undesirable electrode polarization and capacitive impedance. The response of the probe is fed to an electronic analyzer-demodulator. A multiplexer is programmed to scan channels once in 5 s with an intrachannel delay of 5 ms. The analog d.c. output signals of the analyzer from the different electrode pairs are converted to apparent conductance of the foam using a calibration curve based on precision resistors.

A still digital camera (Canon, EOS 350D, 8 Mp) is used to take photographs of the entire container during drainage at 10 min intervals. These images are used to determine volumetrically the instantaneous volumes of the remaining foam and of the drained liquid beneath the foam (serum).

At least three records were acquired at all experimental conditions and the reproducibility is good with an average coefficient of variance (standard deviation/mean) less than 0.1. Pearson correlation coefficients among sampled time-series are above 0.97 whereas average instantaneous signal deviations are around 2%, a value close to the measured signal's noise.

2.4. Data reduction

2.4.1. Volumetric estimations

Foamability (also known as foaming capacity or foam expansion) is expressed volumetrically as a fraction of the initial foam volume, V_{Fo}, over the initial volume of the LP solution which in our case coincides with the initial liquid volume contained in the foam, V_{Lo}:

$$FA_{volume} = \frac{\text{Initial Foam Volume}}{\text{Initial LP solution Volume}} = \frac{V_{Fo}}{V_{Lo}} \quad (1)$$

Foam stability is estimated volumetrically by the time evolution of two quantities. The first quantity is the fraction of the instantaneous foam volume, V_{Ft}, over the initial foam volume V_{Fo}. The second quantity is the fraction of the liquid volume remaining in the foam, V_{Lt}, over the initial liquid volume contained in the foam, V_{Lo}:

$$FSF_{volume} = \frac{\text{Instantaneous Foam Volume}}{\text{Initial Foam Volume}} = \frac{V_{Ft}}{V_{Fo}} \quad (2)$$

$$FSL_{volume} = \frac{\text{Instantaneous Liquid Volume in the Foam}}{\text{Initial Liquid Volume in the Foam}} = \frac{V_{Lt}}{V_{Lo}} \quad (3)$$

The ratio V_{Lt}/V_{Ft} gives the instantaneous global volumetric liquid fraction, β_{volume}, of the entire foam column which in literature has been also termed as foam density.

$$\beta_{volume} = \frac{\text{Instantaneous Liquid Volume in the Foam}}{\text{Instantaneous Foam Volume}} = \frac{V_{Lt}}{V_{Ft}} \quad (4)$$

By comparing Eq. (1) with Eq. (4) it is apparent that Eq. (1) represents the inverse volumetric liquid fraction in the initial foam column.

The above quantities have been widely used for the evaluation of foaming performance from volumetric measurements (e.g., [22,24,26]).

2.4.2. Electrical estimations

In this work, electrical data are used only for the estimation of foam stability. This is given by the time evolution of the fraction of the instantaneous foam conductance, K_{Ft}, over the initial foam conductance, K_{Fo} (e.g., [12,25]):

$$FS_{elect} = \frac{\text{Instantaneous Foam Conductance}}{\text{Initial Foam Conductance}} = \frac{K_{Ft}}{K_{Fo}} \quad (5)$$

2.4.3. Correlation of electrical with volumetric data

In aqueous systems involving a dispersed gas phase, electric current travels only through the continuous aqueous phase. Based on this, it has been realized that the ratio of the electrical conductivity of the dispersion to the electrical conductivity of the continuous phase can be expressed as a function of the volumetric fraction of the liquid in the dispersion. The algebraic form of this function depends drastically on the distribution pattern of the two phases [27]. For a uniformly dispersed system (e.g. a homogeneous foam), the ratio of conductivities is equal to the ratio of the experimentally measured apparent conductances (the inverse of the apparent resistances) regardless of the geometry of the system:

$$\frac{\sigma_{dis}}{\sigma_{liq}} = \frac{K_{dis}^{app}}{K_{liq}^{app}} = \frac{K_{Ft}}{K_L} \quad (6)$$

where σ_{dis} and K_{dis}^{app} denote the conductivity and apparent conductance of the dispersion, respectively, whereas σ_{liq} and K_{liq}^{app} denote the conductivity and apparent conductance of the liquid. The normalization of conductance measurements with respect to the conductance of the liquid constituting the foam not only allows comparison of experimental data with theory but also eliminates errors owing to liquid conductivity variations.

Several algebraic expressions have been proposed to relate the ratio of conductivities to liquid volumetric fraction in uniformly dispersed systems, Fig. 2; cited from [28]. However, there are large discrepancies between models most of which should be attributed to the assumed different structural properties of the dispersions.

Table 3
Electrode pairs, probe code name, electrodes separation distance.

Electrode pairs per probe	Probe code name	Electrode separation distance
AB	LU: long up	3 cm
BD	LD: long down	3 cm
CD	SD: short down	1 cm
AD	LU/LD	6 cm

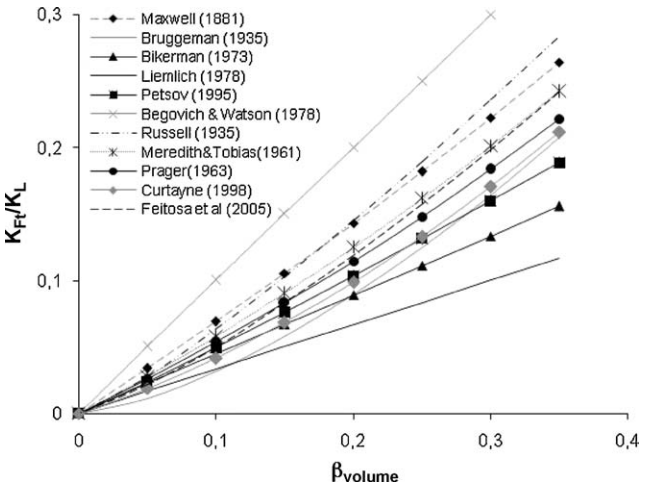

Fig. 2. Correlation of the normalized electrical conductivity, K_{Ft}/K_L, of dispersed systems to their liquid volumetric fraction, β_{volume}, according to selected models from literature.

In the absence of direct evidence, e.g. close-up photos, to allow judging the structure of our foams it is difficult to tell which of the various algebraic expressions is more appropriate in describing our data. For this, we decided to compare electrical and volumetric data in a conventional kinetic fashion where both types of data are plotted against a common dimensionless scale.

3. Results and discussion

3.1. Foaming ability

Fig. 3 presents the foaming ability of the examined solutions as determined by the volumetric technique. Repeatability checks give in all cases an initial liquid fraction variance (stdev/mean) less than 0.03. LPTF solutions exhibit higher foamability than LPTE solutions under all examined conditions. This is also what Alamanou and Doxastakis [1] observed including in their foams the insoluble protein fraction. However, even in the absence of insoluble aggregates it is rather expected that LPTF would perform better since it includes chiefly albumins, whereas LPTE chiefly globulins. Albumins are more flexible molecules that can unfold, extend and deploy at interfaces much faster than globulins and so can reduce more rapidly the dynamic surface tension during foam production. One may argue that a higher protein solubility may also favor foamability. However, the superiority of LPTF holds also at pH 7 where the solubility of both LPIs is alike so it is rather the protein composition that dictates this performance.

At first glance, it is rather surprising, that the foaming ability of LPTE and LPTF is only slightly reduced when the pH becomes

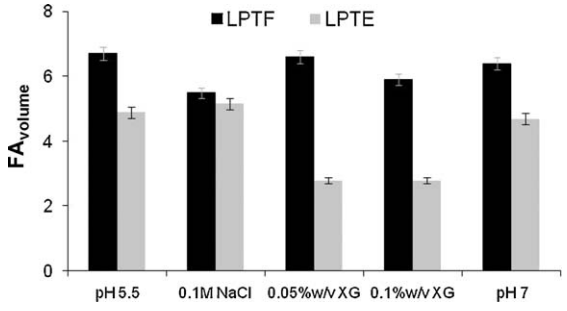

Fig. 3. Foamability of LPTE and LPTF solutions based on volumetric measurements. Error bars stand for standard error of measurements.

7. This is more so for LPTE for which protein solubility at pH 5.5 is about half than at pH 7. This can be so only if in all runs the amount of dissolved proteins is anyway adequate to lower surface tension. Apart from the better solubility, at pH 7 proteins are far from their isoelectric point (p*I*) so are expected to yield better foamability because molecules are more extended and flexible and so can adsorb faster at interfaces. However, this is not observed in the present experiments. It has been argued [29] that criteria other than surface tension must also be taken into consideration to predict foamability. For instance, the structure of molecules and the way they form the interfacial film can play a role. So, the higher the dilatational elasticity of the film the higher the amount of incorporated air. In the above argument one should not ignore the role of bubble size. Intense turbulent mixing, such as during whipping, leads to much smaller bubbles compared to gentle air injection methods [30]. The balance between rheological properties of the bulk phase and of the interface on one side and surface tension on the other, can induce transition regimes of surface mobility that are different for small and large bubbles [31]. More work is needed to clarify this issue.

Addition of salt is expected to increase foamability because of screening of the electrostatic repulsion between molecules. This accelerates protein adsorption and leads to faster decrease of surface tension [32] This effect, however, is strong at pH far from the p*I* and this may explain the small positive effect of salt in LPTE foams. Yet, the situation is counterintuitive with LPTF foams that present lower foamability in the presence of salt. Modern ideas on protein foams, describing protein molecules more in colloidal terms (molecular size, exposed hydrophobicity, net charge) than in traditional polymer/macromolecular terms (capacity to unfold at interfaces) can be useful in resolving this issue [8].

The conventional view regarding the presence of XG is that it reduces the intensity of whipping by increasing the bulk viscosity and so precludes air incorporation into the liquid. However, XG has a more drastic negative effect in LPTE foams where the amount of dissolved proteins is significantly less than in LPTF foams. Thus, it seems that protein–polysaccharide interactions are also important and can at least in part counterbalance the negative effect of the increased bulk viscosity.

3.2. Foaming stability

Fig. 4A–C examine volumetrically the stability of LPTE foams based on the evolution of: (a) the global volume of the liquid contained in the foam, FSL_{volume}, (b) the global volume of the foam column, FSF_{volume}, and (c) the global liquid fraction, β_{volume}, in the foam column. In all runs, the initial rate of liquid withdrawal (Fig. 4A) is higher than the initial rate of foam volume decay (Fig. 4B) so the initial liquid fraction (Fig. 4C) declines steadily. The situation changes after 30 min of drainage (at different moment for each foam) where the liquid withdrawal rate progressively levels-off whereas the foam volume decay rate remains unchanged. As a consequence, the liquid fraction reaches gradually a plateau or even starts rising. Apparently, after 30 min of drainage, considerable liquid fraction gradients exist along the foam column so the global (volumetric) liquid fraction is misleading in appraising foam stability.

XG yields much wetter foams (Fig. 4C). However, only the foam with 0.1% w/v XG is overall more stable than the others, because this XG concentration is adequate to affect bulk viscosity and interfacial rheological properties. Foams with 0.1 M NaCl and at pH 7 are the least stable of all particularly after 20–30 min of drainage. The increased ionic strength and the distance from the p*I* both act to loosen the structure of protein molecules leading to thinner and less stable films. Comparison between the foams with 0.1 M NaCl

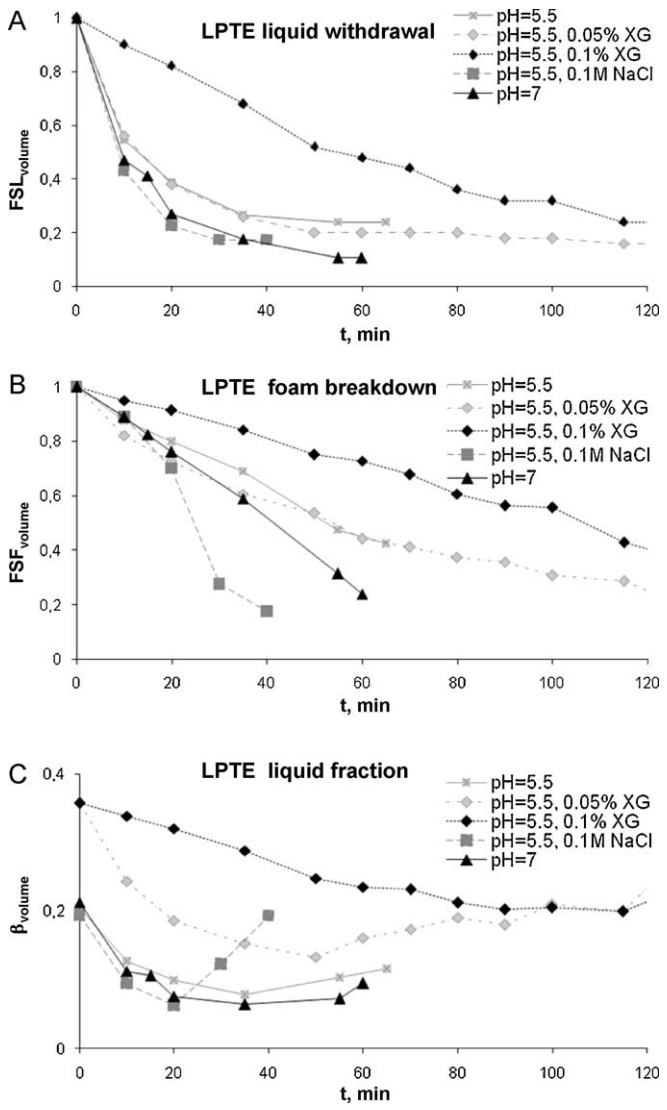

Fig. 4. Foam stability of LPTE solutions based on volumetric measurements.

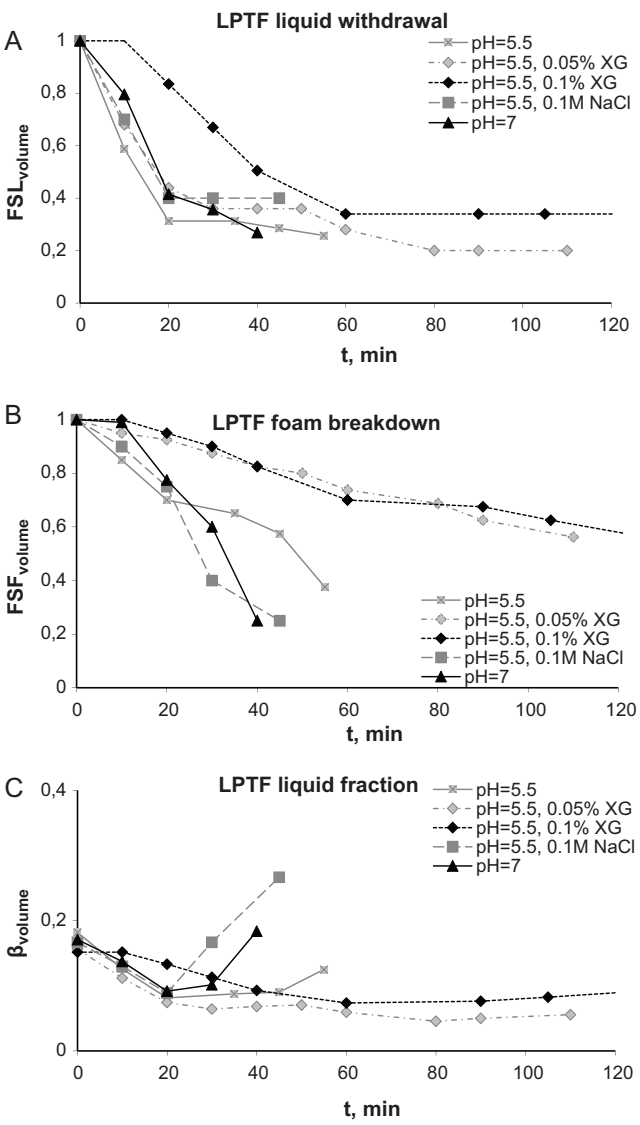

Fig. 5. Foam stability of LPTF solutions based on volumetric measurements.

and with pH 7, shows that the salt has a stronger negative effect than pH on foam volume decay whereas liquid withdrawal rates are comparable.

Fig. 5A–C display the stability of LPTF foams in terms of volumetric measurements. General trends are identical with LPTE foams but there are also some differences. Perhaps the most unexpected difference is that foams with pH 7 and with 0.1 M NaCl are slightly more stable than the foam at pH 5.5 for the first 20–30 min after foam production. In addition, the foam with 0.05% w/v XG has a comparable decay rate (Fig. 5B) with that with 0.1% w/v XG although the liquid withdrawal rates are very dissimilar.

Cross-plotting LPTE and LPTF curves obtained at similar conditions reveals some interesting information (cross-plots are omitted). LPTE and LPTF foams at pH 5.5 present comparable destabilization rates (regarding both liquid withdrawal and foam volume decay). So, invoking the observed higher stability of LPTF foams in the presence of aggregates [1], it appears that aggregates in the LPTE foams may have a stronger destabilizing effect than in the LPTF foams. This is consistent with the notion that aggregates (not completely dissolved protein particles [8]) in LPTE foams have most likely larger sizes since the solubility of LPTE at pH 5.5 is significantly lower than the solubility of LPTF. On the other hand, LPTF foams made at pH 7 as well as with the addition of XG and NaCl are a bit more stable than LPTE foams, especially for the first 30 min of drainage. By analogy with the pH 5.5 foams, one might expect that the presence of aggregates would make LPTE foams further unstable.

Fig. 6A and B present electrical data obtained by three probes (LU, LD, and SD) during drainage of LPTE and LPTF foams at pH 5.5. Data are presented up to 1000 s since within this period a great part of liquid drainage occurs. In all probes, the signal drops fast at the beginning and more gradually later on in a fashion qualitatively similar to the volumetrically observed liquid withdrawal. In addition, the LD probe presents always a slower drainage rate than the LU probe due to hydrostatic effects in the foam. Contrary to the similar global performance of the two LPIs observed volumetrically, local electrical measurements reveal some significant differences. Although the signal of the LD probe is comparable in the two foams indicating a similar liquid fraction at the lower part of the foams, the signal of the LU probe starts to diverge sooner and more intensively in the LPTF foam but levels-off later on. This means that at the upper part of the column, the LPTF foam dries faster at the beginning but much slower later. Thus, a different liquid fraction profile develops along the two foams with the LPTF foam being more heterogeneous in the axial direction.

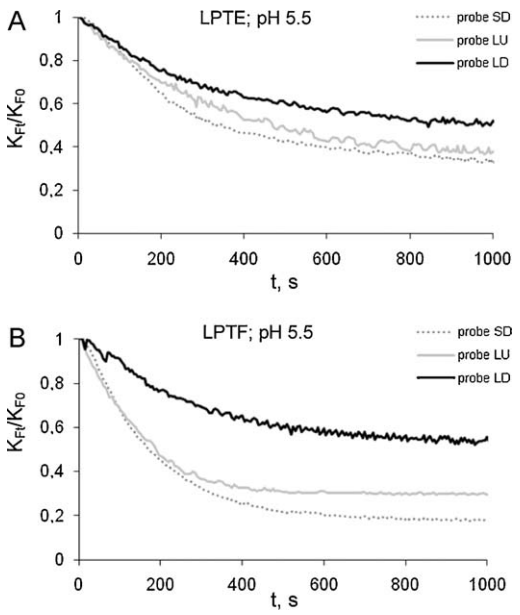

Fig. 6. Foam stability of A) LPTE and B) LPTF solutions for unstable foams at pH 5.5 based on electrical measurements.

The above is confirmed by measurements with the SD probe, the measuring volume of which is confined near the wall of the container. The response of the SD probe is closer to LU probe than to LD probe in both foams. Therefore, the drainage rate at the wall is higher than the cross-sectional average rate measured at the same height. And again, this is more so with the LPTF foam, indicating an appreciable radial liquid fraction profile in the foam column. All in all, it seems that the LPTF foam is less capable than the LPTE foam of maintaining spatial liquid homogeneity although volumetrically the two foams appear to have comparable stability.

The situation changes in Fig. 7 which displays the response of the three probes in the most stable foam examined in this work (LPTE at pH 5.5 with 0.1% w/v XG). In this case, the SD signal coincides with the LD signal indicating a radial liquid content homogeneity in the cross-section of the foam. In addition, there is no sing of drainage measured by both LD and SD probes for some appreciable initial period of time. This is another evidence of the increased stability of this foam. Apparently, electrical measurements can reveal important local features that global volumetric measurements completely miss.

Next, we compare electrical and volumetric data in a non-dimensional kinetic plot, Fig. 8. Both types of data are reduced to a dimensionless scale between 1 and 0 and presented up to 30 min,

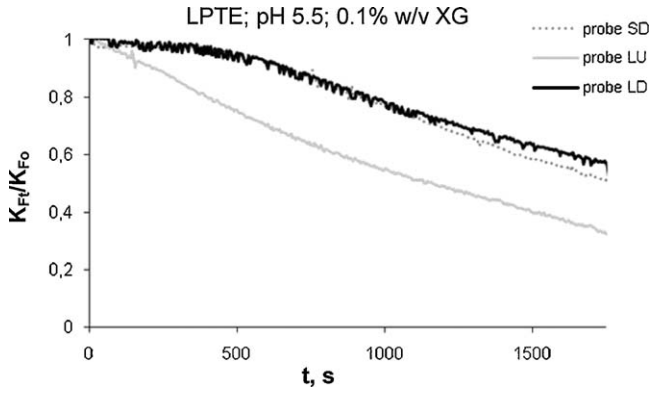

Fig. 7. Foam stability of LPTE solutions for pretty stable foams at pH 5.5 with the addition of 0.1% w/v XG based on electrical measurements.

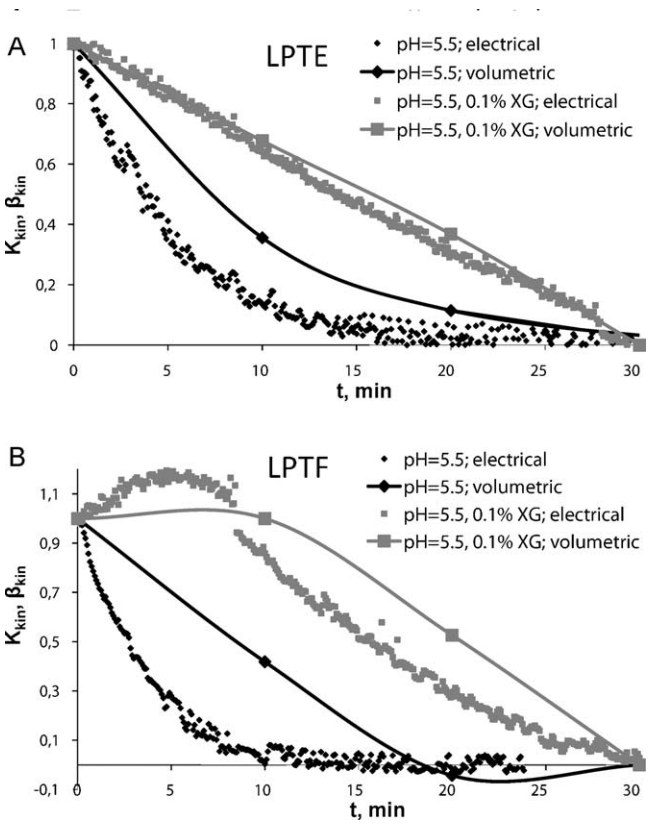

Fig. 8. Kinetic comparison between A) LPTE and B) LPTF foams for two extreme cases: one for unstable foams at pH 5.5 and the other for pretty stable foams at pH 5.5 with the addition of 0.1% w/v XG.

which is the time up to which there is good contact of the liquid with electrodes (as bubbles grow larger the contact gets poorer). To allow meaningful comparisons the measuring volumes of the two techniques must be as similar as possible. The measuring volume of the LU/LD probe is the largest among all probes as it spans about half of the initial foam volume. Thus, data from the LU/LD probe is more suitable in comparing the two techniques Fig. 8A and B contrast pairs of kinetic curves of LPTE and LPTF foams at two extreme cases. One extreme is the curves of unstable foams at pH 5.5 and the other is the curves of stable foams at pH 5.5 with 0.1% w/v XG. For the latter, volumetric measurements agree more with electrical measurements. This is an indication that these foams are quite homogeneous. The situation is different with the unstable foams where electrical data show a faster withdrawal of liquid than volumetric data. The discrepancy between the two techniques implies that a liquid fraction gradient develops rapidly along the foam column. Another interesting feature sensed only electrically is the slight gradual rise of the signal for an initial short period in the stable LPTF foam with 0.1% XG. Such a small liquid fraction rise has been ascribed to bubbles getting larger with time and thus creating a lower tortuosity of the conducting medium [9,14].

4. Conclusions

The two lupin protein isolates recovered by different wet extraction processes – LPTE by isoelectric precipitation and LPTF by ultrafiltration – present satisfactory foaming activity. The combination of global volumetric measurements with local electrical measurements offer distinct advantages in characterizing the foams since each technique delivers information on a different spatial scale. Thus, electrical measurements are capable of depicting local drainage features that the global volumetric measurements

cannot capture. Regarding foamability, LPTF solutions perform better than LPTE solutions. The presence of XG has a strong negative effect in LPTE foams but only a slight effect in LPTF foams. Furthermore, NaCl has a small positive effect on LPTE foams and a small negative effect on LPTF foams. Regarding foaming stability, LPTF foams are globally comparable with LPTE foams at pH 5.5 as measured volumetrically. However, local electrical measurements showed that LPTF foams develop higher liquid content heterogeneity in both the axial and radial directions. Furthermore, XG leads to more stable foams whereas NaCl to less stable foams with both LPTE and LPTF solutions. However, LPTF foams are globally a little more stable than the LPTE foams at pH 7 and in the presence of XG and NaCl. With respect to the effect of aggregates, foamability is better for LPTF than LPTE solutions as was also reported in the presence of insoluble protein aggregates [1] so aggregates do not seem to play a key role. The situation differs regarding foam stability where the two isolates are found to have a comparable global performance with the LPTF performing poorer as regards the spatial liquid content heterogeneity. Since in the presence of aggregates, LPTF was found to perform globally better than LPTE [1] it seems that aggregates have a stronger destabilizing effect in LPTE foams than in LPTF foams. This is in line with the notion that LPTE aggregates can have larger sizes (due to the lower LPTE solubility) than LPTF aggregates.

Acknowledgement

Financial support by the European Space Agency through the project FASES (ESA-AO-2004-PCP-109/ELIPS-2) is gratefully acknowledged. This work is conducted under the umbrella of the COST P21 action: Physics of Droplets.

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