Journal of Food Engineering 150 (2015) 117–124

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Sustainability assessment of oilseed fractionation processes: A case study on lupin seeds

J.A.M. Berghout, P.J.M. Pelgrom, M.A.I. Schutyser, R.M. Boom, A.J. van der Goot *

Food Process Engineering Group, Wageningen University, PO Box 17, 6700AA Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 29 September 2014
Received in revised form 13 November 2014
Accepted 16 November 2014
Available online 24 November 2014

Keywords:
Energy consumption
Dry fractionation
Aqueous fractionation
Water consumption
Exergy analysis
Lupin protein

ABSTRACT

Traditional ingredient production focusses on high purity and yield, resulting in energy- and resource-intensive fractionation processes. We explored alternative fractionation routes for oilseeds by focussing on functionality and optimal resource use. Lupin seeds were taken as model material because they are rich in protein and oil and they can be grown in moderate climate conditions. Dry fractionation yields functional protein-enriched flours without using water, consumes the least energy and exergy losses are low. Purer protein fractions are obtained via conventional wet or aqueous fractionation, but these processes require large amounts of water and an energy-intensive drying step. With the use of exergy analysis, we demonstrate that water and energy consumption can be reduced by replacing drying steps with concentration steps and by combining dry and aqueous fractionation processes. Finally, by valorising side streams, the exergetic efficiency of *all* fractionation processes increases.

1. Introduction

Plant-based diets are more sustainable than animal-based diets (Pimentel and Pimentel, 2003). To replace animal-based protein products, plant-based materials are needed that meet the nutritional, functional and textural properties of animal-based products (Hoek et al., 2011). Animal-based products consist of water, protein and fat. Pulses, legumes and oilseeds contain these components as well, but they also contain carbohydrates, like dietary fibre, starch and sugar, and oil. Promising oilseeds for plant-based materials are soybeans, lupin seeds, canola meal, and sunflower seeds or sunflower meal because they are rich in protein, oil and they are low in starch (Day, 2013). Especially lupin seeds are of interest because they have the highest protein content in comparison with other oilseeds and they can be grown in moderate climate areas like Northern Europe. To better mimic animal-based products, the carbohydrate content has to be reduced, which leads to the necessity of refining. This is generally carried out by wet fractionation, aiming at complete separation and high purity of the components. Unfortunately, conventional wet fractionation processes consume solvents, energy and water, which negatively impact the sustainability of the production of plant-based materials (Apaiah et al., 2006). It leads to a need for milder fractionation alternatives that consume less solvents and energy.

A milder wet fractionation method is aqueous fractionation, where the use of organic solvents is omitted (Aguilera et al., 1983; Campbell et al., 2010; Jung, 2009). In a previous paper we showed that aqueous fractionation of lupin seeds yields protein isolates (PI's) with 2–7 g oil/100 g PI that has similar functionality as PI's obtained with conventional wet fractionation (Berghout et al., 2014). Wet and aqueous fractionation of lupin seeds yield wet PI's that have to be stabilized to prevent microbial and chemical spoilage, which is often accomplished through drying steps. Drying consumes a lot of energy while it can detrimentally affect protein functionality (Hu et al., 2009; Joshi et al., 2011; Liao et al., 2013). A less energy intensive process is ultrafiltration, however this leads to a reduced microbial and chemical stability and therefore the PI's have to be processed shortly after fractionation to prevent spoilage. We investigated the potential of replacing the drying step in the process with a concentration step. Dry fractionation is a sustainable alternative for wet and aqueous fractionation because it avoids the use of water and consumes less energy (Schutyser and van der Goot, 2011). In addition, the fractions have been processed in a milder way because they have not been wetted and subsequently dried, and therefore retain their original functionality (Pelgrom et al., 2014, 2013; Schutyser and van der Goot, 2011). Dry fractionation involves fine milling and air classification. The classification is based on particle size and density differences of the particles obtained after milling. Pelgrom et al. (2014) showed that dry fractionation of lupin seeds

Abbreviations: PI, protein isolate; FP, fibre-rich pellet; SSF, soluble solids fraction; CEE, chemical exergy efficiency.

* Corresponding author. Tel.: +31 317 480852.
E-mail address: atzejan.vandergoot@wur.nl (A.J. van der Goot).

http://dx.doi.org/10.1016/j.jfoodeng.2014.11.005
0260-8774/

provides protein-enriched flours with protein contents of 53.5 g protein/100 g protein concentrate (N × 5.7) and unique protein functionality. The protein-enriched flours can be further refined into PI's by aqueous fractionation in case a higher protein content is desired. Separating the raw materials into pure ingredients is however not efficient because no end product is composed of one pure ingredient. It may be more efficient to produce less pure fractions that can be directly used for an application, consequently avoiding the need for other pure ingredients. Focusing on molecular purity, as is done with PI's, also increases the amount of side streams that are produced. These side streams still contain valuable ingredients that can potentially be used for other (food) applications, which can contribute to a more sustainable future (Aiking, 2011; Mirabella et al., 2014). That is why we evaluated the effect of valorising these streams on sustainability of fractionation processes.

Exergy is an environmental indicator that is demonstrated to be useful for development of sustainable products and processes, like for the minimization of the use of resources and the emissions of processes (Bastianoni et al., 2005; Dincer and Rosen, 2004; Rosen et al., 2008). Exergy, also called available work, is a thermodynamic state variable that is based on the second law of thermodynamics (Apaiah et al., 2006) and it shows the potential work that can be done by exchange with a reference environment (Rosen et al., 2008). Rosen et al. (2008) showed there is a positive relation between exergy efficiency and environmental impact.

The objective of this paper is to assess the impact of producing protein-enriched fractions using dry, wet and aqueous fractionation. The production routes are evaluated for mass of solvents used, for energy consumed and for exergy losses and efficiencies. It is evaluated whether a combination of dry and aqueous fractionation processes increases the sustainability of fractionation of lupin seeds. In addition, coupling fractionation and product application, i.e. skipping the final drying step, is discussed. A final optimisation of individual unit operations was outside the scope of this study.

2. Material and methods

2.1. System boundaries

Fig. 1 shows the materials and products for all fractionation processes chosen for analysis. The impact of the processes was evaluated based on the main differences between them. This means that for comparing dry and wet fractionation, the use of water is evaluated and for the conventional wet and aqueous fractionation process the use of an oil extraction step is evaluated. The combination of both processes will be evaluated as well because the products obtained with dry fractionation are not as pure as with wet fractionation.

2.2. Fractionation processes

Dry fractionation was performed as described by Pelgrom et al. (2014). Lupin seeds (*Lupinus angustifolius*) were obtained from LI Frank (Twello, the Netherlands). The seeds were pre-milled into grits with a pin mill LV 15 M (Condux-Werk, Wolfgang bei Hanau, Germany) and were then milled into flour with a ZPS50 impact mill (Hosokawa-Alpine, Augsburg, Germany) with classifier wheel speed set at 1000 rpm, mill speed of 8000 rpm, and air flow at 80 m^3/h. The flour was fractionated with an air-classifier set at 10,000 rpm and air flow at 80 m^3/h, which resulted in a fine and a coarse fraction.

Conventional wet fractionation was performed as described in Berghout et al. (2014). Full fat lupin flour was defatted with petroleum ether (boiling range 40–60 °C) with a sample-to-solvent ratio of 1:6 on a fully automated Büchi extraction system B-811 LSV (Büchi Labortechnik AG, Flawil, Switzerland). The defatted lupin flour was then dispersed into tap water using a sample-to-solvent ratio of 1:15. The pH of the dispersion was set to 9 with 1 mol/L NaOH and the dispersion was stirred at 20 °C for 1 h. The dispersions were centrifuged at 11,000*g* and 20 °C for 30 min. The supernatant was separated from the pellet and the pH of the supernatant was adjusted to pH 4.5 with 1 mol/L HCl. The protein-rich supernatant was stirred at 20 °C for 1 h and subsequently centrifuged at 11,000*g* and 20 °C for 30 min. The supernatant was separated from the pellet and the pellet was rinsed twice with 50 mL Millipore water and kept at 20 °C for 1 h and then centrifuged at 10,000*g* and 20 °C for 10 min to remove impurities. The protein pellet was stored in the freezer at −20 °C for freeze drying.

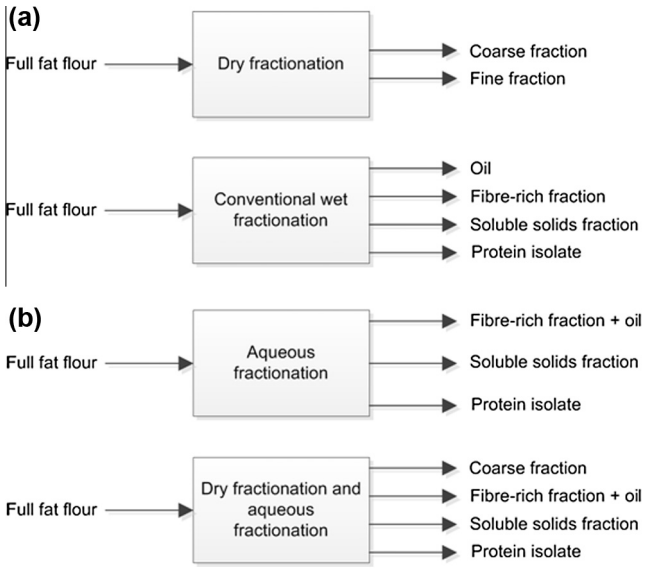

Fig. 1. Fractionation processes: dry fractionation, conventional wet fractionation, aqueous fractionation and a combination of dry and aqueous fractionation.

Aqueous fractionation omits the oil extraction step used during the conventional wet fractionation process and was performed as described previously by Berghout et al. (2014). The full fat lupin flour was dispersed into tap water using a sample-to-solvent ratio of 1:15. The rest of the fractionation process was the same as for the conventional wet fractionation process, except that the whole process was performed at 4 °C. Aqueous fractionation was also performed with the fine fraction that was obtained after air classification. This process is the same as described for the full fat flour.

2.3. Data collection

Compositions and masses of all fractions are based on the experimental work. The amount of PI produced was set to 1000 kg (1 ton). Aqueous fractionation yields PI's that contain oil, a fibre-rich pellet that contains most of the oil and a soluble solids fraction that does not contain oil. For ease of comparison, it was assumed that the PI's (in contrast to the protein-enriched flours) obtained with the different fractionation processes had similar composition, i.e. 83 g protein/100 g, 5 g water/100 g, 10 g carbohydrates/100 g and 2 g mineral residue/100 g. Data of equipment like a spray drier, an oil extraction system and a cooling system are based on equipment often used on pilot scale. The ratio of sample-to-solvent in the oil extractor is based on lab scale experiments performed at the German Fraunhofer Institute in Freising (Bader et al., 2011).

2.4. Protein recovery and purity

The protein content of each fraction was calculated from the nitrogen content (N × 5.7), determined with the Dumas