Ultrasonics Sonochemistry 31 (2016) 319–329

Contents lists available at ScienceDirect

Ultrasonics Sonochemistry

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

Ultrasound induced green solvent extraction of oil from oleaginous seeds

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ARTICLE INFO

Article history:
Received 7 December 2015
Accepted 9 January 2016
Available online 11 January 2016

Keywords:
Ultrasound
Extraction
Oilseed
Green impact
Degradation
Unit operation

ABSTRACT

Ultrasound-assisted extraction of rapeseed oil was investigated and compared with conventional extraction for energy efficiency, throughput time, extraction yield, cleanness, processing cost and product quality. A multivariate study enabled us to define optimal parameters (7.7 W/cm^2 for ultrasonic power intensity, 40 °C for processing temperature, and a solid/liquid ratio of 1/15) for ultrasound-assisted extraction of oil from oilseeds to maximize lipid yield while reducing solvent consumption and extraction time using response surface methodology (RSM) with a three-variable central composite design (CCD). A significant difference in oil quality was noted under the conditions of the initial ultrasound extraction, which was later avoided using ultrasound in the absence of oxygen. Three concepts of multistage cross-current extraction were investigated and compared: conventional multistage maceration, ultrasound-assisted maceration and a combination, to assess the positive impact of using ultrasound on the seed oil extraction process. The study concludes that ultrasound-assisted extraction of oil is likely to reduce both economic and ecological impacts of the process in the fat and oil industry.

1. Introduction

Rapeseed oil is the third most widely consumed vegetable oil worldwide after palm and soybean, and ranks first in Europe for frying oil, margarine and salad dressings [1,2]. The rapeseed oil production process involves several steps including preparation of seeds, mechanical pressing and solvent extraction of the press cake (Fig. 1) [2].

The oldest method for oil recovery from seeds is pressing to squeeze the oil out of the solid residue [3]. However, matrices containing more than 30% oil, such as rapeseed, which contains nearly 50%, require more than simple pressing to recover all the oil available in the seed. Conventional processing begins by a conditioning step to increase seed plasticity by warming to 50–60 °C. Seeds are then flaked between smooth rollers to increase the surface area and help release oil. The flakes undergo a cooking step lasting 20–60 min, which brings the temperature into the range 90–120 °C. This step produces significant changes in the cell, especially by destroying oil bodies and causing oil droplets to merge and migrate across cell walls. As a result, the mechanical extraction by pressing that follows the cooking step removes 65–70% of the oil contained in seeds. It permits to continue the cell wall disruption needed to obtain a high rate of oil recovery in press cake [4,5]. The press cake then undergoes solvent extraction. This step is performed in countercurrent extractors using hydrocarbon solvents, with 40–60% *n*-hexane, sourced from fossil resources and registered under the REACH Regulation as a category 2 reprotoxic and a category 2 aquatic chronic toxic substance [6]. Reducing the amount of hexane used in oil processing while keeping the same extraction performance has become desirable and is a key issue for industries for economic and ecological reasons.

Over the past few years, much interest has been paid to the applications of ultrasound (US) in food science and technology [7–10]. Applications of US generally involve processes that can enhance rates, improve quality and/or safety, and reduce processing time. A growing trend is the possible application of US for the extraction and promotion of natural compounds of interest [11] for industry [12,13]. The benefits of US are attributed to acoustic cavitation: micro-bubbles created in a liquid phase when subjecting a mixture to US will grow and oscillate quickly before collapsing due to pressure changes [14,15]. These violent implosions will fragment or disrupt the surface of the solid matrix, enhancing mass transfer and accelerating diffusion. Several studies suggest that

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http://dx.doi.org/10.1016/j.ultsonch.2016.01.011
1350-4177/

Nomenclature

A	ultrasonic intensity (W/cm^2)	V	overflow phase (V = E + S)
B	temperature (°C)	L	underflow phase (L = E + I + S)
C	solid/liquid ratio	F	feed (rapeseed press cake)
CV	conventional extraction	M	ternary mixture point (M = F + S)
E	solute (assumed as oil)	SFA	saturated fatty acids
I	inert phase (solid)	MUFAs	mono unsaturated fatty acids
S	solvent phase (hexane)	PUFAs	poly unsaturated fatty acids

ultrasonic technology is an effective tool for vegetable oil extraction from seeds [16–19].

This paper describes an investigation on the influence of US for the extraction of rapeseed oil. Rapeseed oil is rather difficult to extract compared with sunflower oil, for example [20]. This is attested by the levels of residual oil in rapeseed meal, with residual oil contents in the range 1.8–4.1% [21] against 1.0–2.5% in sunflower meal [22]. These results are obtained at the cost of significant constraints on the preparation step (cooking), which could be reduced by an intensification treatment. The ultrasonic extraction parameters such as ultrasonic power intensity, extraction temperature and solid/liquid ratio for rapeseed oil extraction were optimized with the response surface methodology (RSM) using a three-variable central composite design (CCD). Extracts were qualitatively and quantitatively analyzed by GC-FID to investigate the influence of US on yield and oil quality. Three concepts of multistage cross-current extraction were then investigated and compared: conventional multistage maceration, US-assisted maceration, and a combination thereof [23] to highlight the impact of using US. The study was extended by a preliminary assessment on economic, energy and ecological impacts comparing conventional and US-assisted extraction.

2. Materials and methods

2.1. Chemicals

Rapeseed, of the Astrid breeding line (Euralis Semences), was provided by the Technical Institute for Oilseeds (Terres Inovia,

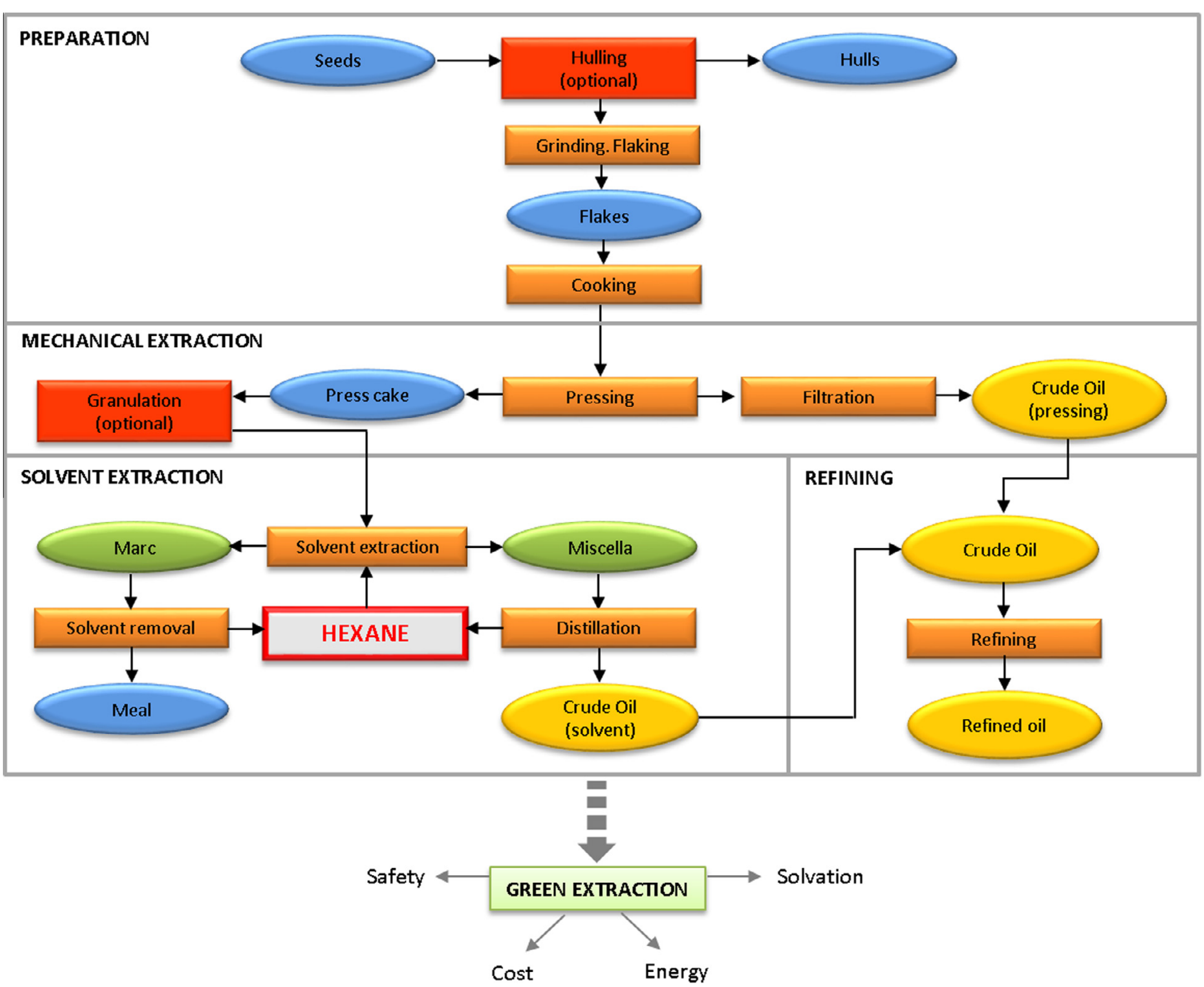

Fig. 1. Conventional processing procedures for rapeseed oil extraction towards greener extraction.