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Oilseeds sorption isoterms, mechanical properties and pressing: Global view of water impact

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ABSTRACT

The aim of this study was to investigate the interaction between water and oleaginous seeds (rapeseed, flaxseed and sunflower) and its consequence on processing (pressing). Sorption isotherms of whole seeds, hulls and embryos were established and highlight the uniform behaviour of seed fractions towards water. Seed expression is highly influenced by seed moisture content and water activity in unidirectional and screw presses. Transposability of discontinuous pressing to continuous screw presses has been assessed. Seed mechanical properties are affected by water activity and moisture content. Moreover, fracturability evolution according to moisture content gives indication about oil yield dependency from water content and minimal elasticity corresponds to maximal oil yield for flaxseed. The relations established between sorption isotherms, drying behaviour, mechanical properties and pressing (unidirectional and continuous) leads to global view of water impact on seed processing.

1. Introduction

The processing of oilseeds to obtain oil is traditionally done by mechanical pressing followed by extraction with organic solvent (i.e. hexane) (Laisney 1996). The mechanical pressing step is strongly influenced by the water content of the treated seeds (Lanoisellé and Bouvier 1994). The impact of moisture on the pressing of oilseeds was noted for both discontinuous (unidirectional) and continuous pressing (Archimedes' screw). Depending on the oilseed specie, an increase or a decrease of oil yield according to water content was observed (Lanoisellé 1995; Singh et al. 2002; Zheng et al. 2003; Martínez et al. 2008; Smith and Kraybill 1933). For unidirectional pressing of flaxseed, an oil yield decrease (54.7–4.4%) was observed for moisture content increase from 8% to 16% (Dedio and Dorrell 1977). For lower moisture contents (0–10%) Willems et al. (2008) noticed optimal oil yield for moisture content around 5–7%. For rapeseed increase in oil yield according to moisture content was reported by Koo (1942) in a moisture range from 3% to 12%. Nevertheless, for all these studies, seed specie and cultivar as expression conditions are different so no general conclusion can be formulated. For continuous expression in expeller, the case is similar with a strong impact of specie (Savoire et al. 2013). For flaxseed and rapeseed, an oil yield decrease with moisture content was highlighted (Vadke and Sosulski 1988; Zheng et al. 2003). It can be presumed that each oilseed species has its own optimal moisture content which maximizes oil yield. In pressing studies, expression is considered in unidirectional presses or screw presses but the correlation between seed behaviour according to moisture content are not available. So hypotheses for explaining the observed behaviour are only consistent with one of both technologies. Moisture effect is attributed by most authors to the lubricant role that water plays in the flow of seeds along a screw press (Schwartzberg 1997) or to modifications of the seeds textural properties.

The textural (mechanical) seeds changes due to moisture content have been studied by some authors on soybean (Bilanski, 1966) or sunflower (Sharma et al., 2009; Gupta and Das 2000). These studies highlight a decrease of the force required to initiate rupture of seed coat, seed hull or seed kernel with the increase of water content. Nevertheless practically workable correlations between moisture content, textural changes and expression process are still missing.

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Water role within raw material can be characterized as moisture content. This parameter reflects the total amount of water present. Another parameter characterizing water behaviour is water activity. It is defined as the relative humidity of air in equilibrium with the product. At low water activities, biochemical reaction and microorganism growth are slow down. This particularity enables the conservation of products. Moisture content and water activity are linked together through sorption isotherms at constant temperature (Labuza 1968). Sorption isotherms curves present different shapes depending of the product. For oilseeds, type II isotherms are described (Al-Muhtaseb et al. 2002). Such isotherms can be modelled using different mathematical representations. GAB model (Guggenheim – Anderson – de Boer) is commonly used to describe oilseeds sorption isotherms. From sorption isotherm interpretation, distinction between free and bound water can be realized. Bound water is defined as water molecules presenting strong interaction with matrix whereas free water presents weak bond with the matrix. Then free water is available for reaction whereas bound water is unavailable for chemical reactions and is relatively hard to remove during drying (Al-Muhtaseb et al. 2002). More precise distinction could be operated considering water/matrix interactions. Some authors distinguished structural water, multilayer water (surface or hydration) and free (or bulk) water (Sacchetti et al. 2014). Another approach is based on the freezable or unfreezable water (Pham 1987).

The aim of this study is to evaluate the interactions between water and oilseeds and to investigate the role of water in the expression of oilseeds. For this purpose two approaches are compared: the classical approach whereas water impacts the process through its overall content in the product (moisture content) and an original approach based on the availability of water in the seeds (water activity). The distribution of water within the oilseeds, the pressing behaviour and mechanical properties will be correlated to better understand seed water interactions and their influence on expression process.

2. Materials and methods

2.1. Raw material

Rapeseed, Beluga variety, harvested in 2006, and sunflower, Soltis variety, harvested in 2006 were provided by CETIOM; flaxseed, Baladin variety, harvested in 2007 was provided by Laboulet Semences. The native seeds composition (moisture and oil content), seed dimensions and mass repartition between hull and kernel (embryo) are presented in Table 1.

2.2. Wetting method and sorption isotherms

Sorption isotherms of the seeds have been studied at 25 °C following two different approaches: moisture content conditioning and water activity conditioning.

2.2.1. Moisture content conditioning

Conditioning in water content was achieved by whole seed drying in a ventilated oven (CV.300.FHP.2M20, Firlabo, France) at 35 °C to residual water content lower than 4%. The water content was adjusted to the desired value by spraying deionized water on the whole seeds. The quantity of water sprayed was calculated to obtain after hydration the desired moisture content. After spraying and in order to obtain equilibrium, the whole seeds were placed in sealed bags at 4 °C and regularly mixed for a week (AFNOR, 1987). After equilibration and before sorption studies, sealed bags were stored at 25 °C for at least two days. In parallel, some whole seeds were conditioned by hydration at 12% moisture content using the same methodology as previously but without drying. The 12% moisture content whole seeds were then dried in the ventilated oven at 35 °C until the desired moisture content was reached.

2.2.2. Water activity conditioning

For seed water activity conditioning, the method of microclimates was used (Kaya and Kahyaoglu 2006). The saline saturated solutions were as follows (values in brackets represent the relative humidity of air in equilibrium with the salt solution at 25 °C): LiCl (11.3), CH_3COOK (22.5), $MgCl_2$ (32.8), K_2CO_3 (43.2), $Mg(NO_3)_2$ (52.9), $CoCl_2$ (64.9), NaCl (75.3) and KCl (84.3). The whole or crushed seeds, divided in samples of about 16 g, were set to equilibrate in hermetic boxes in presence of a saline saturated solution. Seeds weight was recorded every week and seeds were mixed to obtain regular conditioning. Seed were conditioned until constant weight (at least 3 weeks) at 25 °C. Different batches were used during this study highlighting slight difference in final moisture content and water activity.

2.2.3. Sorption isotherms modelling

Different models describing sorption isotherms are available. According to Lomauro et al. (1985b), the GAB model (Guggenheim–Anderson–de Boer) is the most adequate model for oilseeds (Eq. (1)).

$$M_w = \frac{ABC \cdot a_w}{(1 - B \cdot a_w)(1 - B \cdot a_w + BC \cdot a_w)} \tag{1}$$

where M_w is the water content (db), a_w is the water activity and A, B and C are constants.

The model constants were determined using nonlinear square fit (TableCurve 2D, Systat Software Inc., CA, USA).

In addition to regression coefficient R^2, mean relative percentage deviation modulus (P) were determined using Eq. (2). P (%) is widely adopted throughout the literature, with a modulus value below 10% indicative of a good fit for practical purposes (Lomauro et al. 1985a).

$$P = \frac{100}{n}\sum_{i=1}^{n}\frac{|(M_i - M_{Pi})|}{M_i} \tag{2}$$

Table 1
Seeds characteristics.

	Rapeseed (Beluga 2006)	Sunflower (Soltis 2006)	Linseed (Baladin 2007)
Moisture content (%db)	5.93 ± 0.02	6.45 ± 0.02	6.2 ± 0.3
Oil content (%db)	44 ± 2	49 ± 2	43.2 ± 0.8
Hull (%)	17	22	43
Embryo (%)	83	78	57
Thousand seeds weight (g)	4.6 ± 0.4	97 ± 8	8.1 ± 0.3
Seed length [a] (mm)	1.9 ± 0.1	13.2 ± 0.6	4.9 ± 0.3
Seed width (mm)	–	6.1 ± 0.8	2.4 ± 0.3
Seed thickness (mm)	–	4.2 ± 0.6	1.0 ± 0.1

db: dry basis,
[a] For rapeseed, length corresponds to the seed diameter.