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Review

Challenges and opportunities for new industrial oilseed crops in EU-27: A review

Federica Zanetti[a], Andrea Monti[a,*], Marisol T. Berti[b]

[a] Department of Agricultural Sciences, University of Bologna, Viale G. Fanin 44, Bologna, Italy
[b] Department of Plant Sciences, North Dakota State University, Fargo, ND, USA

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ABSTRACT

The growing demand for renewable feedstock as a substitute for petroleum-derived products offers a unique opportunity for conventional and new oilseeds in Europe. This review compares twenty-four oilseed species relative to oil composition and potential adaptability to different regions of Europe. Widely cultivated species, such as oilseed rape (*Brassica napus* L.), sunflower (*Helianthus annuus* L.), and flax (*Linum usitatissimum* L.), are compared with new species, some of which are well documented in literature, while others are still underdeveloped. The possible geographical allocation in Europe is discussed taking into account physiological and agronomical constraints. Only vernonia (*Vernonia galamensis* L.) and stokes aster (*Stokesia* spp.) appear unsuitable to European environments due to obligated photoperiod requirements. Species such as *Cuphea* spp., echium (*Echium plantagineum* L.), borage (*Borago officinalis* L.), and euphorbia (*Euphorbia lagascae* L.) have still considerable physiological constraints, e.g., lack of seed retention, seed dormancy, and indeterminate growth. The scenario for honesty (*Lunaria annua* L.), lesquerella (*Physaria fendleri* L.), field pennycress (*Thlaspi arvense* L.), and calendula (*Calendula officinalis* L.) is less clear, as the proper agronomic management is still greatly unknown. Finally, Ethiopian mustard (*Brassica carinata* L.), brown mustard (*B. juncea* L.), crambe (*Crambe abyssinica* Cranz), meadowfoam (*Limnanthes alba* L.), and camelina (*Camelina sativa* L.) emerged as mature oilseed crops for large-scale cultivation and commercialization. Coriander (*Coriandrum sativum* L.), cardoon (*Cynara cardunculus* L.), safflower (*Carthamus tinctorius* L.), hemp (*Cannabis sativa* L.), and castor bean (*Ricinus communis* L.), are cultivated crops worldwide, and their re-introduction into Europe, could probably increase the number of oilseed crops cultivated in a short term.

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* Corresponding author. Tel.: +39 0512096653.
E-mail address: a.monti@unibo.it (A. Monti).

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1. Introduction

Non-food uses of plant-derived oils have attracted growing interest during the two past decades with new markets being expanded, as petroleum products have been replaced with new renewable industrial products (Hill, 2000; Schneider, 2006; Wittkop et al., 2009). Oilseeds have the built-in capacity to synthesize highly complex molecular structures that can be used by the industry to displace significant amount of petroleum oil-derived compounds (Carlsson, 2009). Substituting petroleum with plant-derived oils as feedstock for different industries can make a substantial impact.

In Europe, the non-food industrial applications of plant-derived oils represent only 11% of the total use. Food usages make up the remaining 89%. This amount of non-food use lags behind industrialized countries, where the non-food share is 14% (Metzger and Bornscheuer, 2006). This lower use for non-food applications is probably related to the current high imports of raw oils in Europe, indicating that the EU domestic production is not sufficient for satisfying the demand for food or non-food applications (FAOSTAT, 2013), which is increasing the interest toward oilseed crops. Traditionally, the oleochemical industry in North America, Western Europe, and Japan was based on local or imported oils and fats, but this has changed since countries in South East Asia, in particular Malaysia, have become major producers of native raw materials such as palm oil (*Elaeis guineensis* L.).

Presently, the majority of plant-derived oils (approx. 80%) are used for health-food products, however, significant quantities (~14%) serve industrial needs such as surfactants, plasticizers, emulsifiers, detergents, lubricants, adhesives, cosmetics, oleochemicals, and fuels (Carlsson, 2009; Metzger and Bornscheuer, 2006). Actually, these are not new uses; castor bean oil, for example, has been used for cosmetics and lighting since Egyptian times (Franz, 1988; Scarpa and Guerci, 1982; Weiss, 2000). Before the petrochemical industry boom, plant oils and animal fats were the only known sources of raw materials for illumination and lubricants.

The present use of 'pure' seed oils (raw oils, not chemically modified) is still restricted to few applications such as lubricants for chainsaws, concrete-mold release oils, and others. Most plant-derived oils are used as raw materials for the production of chemical compounds by hydrogenation, inter- and trans-esterification, or fractionation in order to obtain desired final products (Gunstone et al., 2007a).

About 90% of the plant-derived oils in the world comes from only a few crops (FAOSTAT, 2013). These oils predominantly contain fatty acids (FAs) with linear-C chains of 16 and 18 carbon atoms, such as palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) acids (Gunstone and Harwood, 2007b). Among the most common sources of oils, palm kernel and coconut (*Cocos nucifera* L.) have shorter-chain FAs (i.e., C12:0 in coconut and C14:0 in palm kernel). Nevertheless, other oilseed crops containing unusual FAs, and/or those characterized by new and interesting functionalities have the potential to be grown in Europe (Baumann et al., 1988; Gunstone, 2001). For example, oils containing unusual FAs, such as, hydroxylated or conjugated-double bonds in the alkyl-chain, could be of particular interest as a suitable raw material for production of chemicals needed in the industry. Such oils could include these derivatives from calendula, lesquerella, vernonia, euphorbia, castor bean, and flax.

Vernonia is characterized by a high content of vernolic acid (a fatty acid already in epoxydized form), from which it is easy to obtain polyvinyl chloride (PVC) and shorter-chain FAs derivatives (C8–C12). Lesquerella (*Physaria fendleri* L.) is rich in lesquerolic acid (hydroxy FA), homologous of ricinoleic acid, normally used for lubricant formulation due to its polarity in the mid-chain position, and also for the production of short-chain FAs (C8–C10) (Al-Shehbaz and O'Kane, 2002).

Cardoon and safflower have been attracting growing interest in Italy for the bio-plastic industry, a sector which is predicted to increase at almost 18% per year (Eni, 2011). The project, to be completed by 2018, consists of seven new plants for an integrated-chain production from vegetable oil to bio-plastics along with bio-lubricants and bio-additives for elastomers.

The majority of the above-mentioned crops have not been cultivated extensively in Europe while some of these crops (e.g., castor bean and flax) were grown in the past for several purposes and then abandoned (Merrien et al., 2012).

The EU community has always demonstrated an interest in oil crops, suitable for the replacement of petroleum-based chemicals, in order to reduce the EU's dependence on imported and non-renewable feedstocks. Significant investments in R&D projects on non-food oil crops during the last 20-years, also demonstrate that interest (Table 1).

We have reviewed twenty four promising oilseed crops with the aim at analyzing the potential of non-food oil crops in Europe (EU-27) through evaluating possible barriers, agronomic and physiological pros and cons for a large-scale commercial development. Finally, a tentative picture of oilseed crop land allocation in Europe has been provided based on crop requirements and land suitability.

2. Novel and old sources of vegetable FAs

Rapeseed (OSR) and sunflower, covering about 60% of the total area presently cultivated with oil crops in EU-27 (FAOSTAT, 2013), were included as baseline for comparing new promising oilseed crops (Table 2). The interest toward new applications of modified fatty acid profile of rapeseed and sunflower, such as high oleic acid rapeseed (HOR), high erucic acid rapeseed (HEAR), high-oleic–low linolenic acids rapeseed (HOLL), and high oleic acid sunflower (HOS) is increasing (Baux et al., 2011; Brandle and McVetty, 1989; Conrood et al., 2008; Friedt et al., 2003; Garcés et al., 1989; Soldatov, 1976).

In order to facilitate the reading of this review, crops were grouped according to the length and saturation of the C-chain for the main FAs contained in the seed oil (Table 2): (1) long-chain FAs (C > 20); (2) short- to medium-chain FAs (C10–C14); (3) hydroxylated FAs; (4) epoxydized and conjugated FAs; (5) PUFAs (poly unsaturated FAs); and (6) MUFAs (monounsaturated FAs). PUFAs were further divided into two sub-categories based on double-bond position: α-linolenic or γ-linolenic.

2.1. Long-chain FAs

High erucic acid rapeseed, and to a lesser extent *Brassica juncea* and *Brassica carinata*, can be considered mature crops for industrial