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Biotechnological Camelina platform for green sustainable oleochemicals production☆

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Abstract – Climate change is forcing our societies to undertake socioeconomic changes to mitigate greenhouse gas emissions, primarily carbon dioxide, which continue to rise globally. Governments are applying policies to offset carbon emissions, despite the significant economic impact. Biotechnology offers solutions to dampen this impact, particularly in agriculture and industry, where plant biotechnology enhances production efficiency while reducing environmental impact. *Camelina sativa*, a climate-flexible oilseed crop with low agronomical exigence, offers promising alternatives to petroleum-derived oils. Oil derived from camelina seeds has the potential to substitute petroleum as the feedstock for the production of oleochemicals, which are compounds derived from vegetable or animal oils and/or petrochemical feedstock. The deep knowledge of the camelina genome, together with the optimized process to obtain genetically engineered camelina lines with on-demand modified oils, makes this oilseed crop a workhorse to counteract the environmental impact derived from human activity.

Keywords: Biotechnology / *Camelina sativa* / environment / oleochemical / sustainability

Résumé – La cameline, plate-forme biotechnologique pour la production d'oléochimie verte et durable. Le changement climatique force nos sociétés à entreprendre des changements socio-économiques pour atténuer les émissions de gaz à effet de serre, principalement le dioxyde de carbone, qui continuent d'augmenter à l'échelle mondiale. Les gouvernements appliquent des politiques pour compenser les émissions de carbone, malgré l'impact économique significatif. La biotechnologie offre des solutions pour atténuer cet impact, notamment dans l'agriculture et l'industrie, où la biotechnologie végétale améliore l'efficacité de la production tout en réduisant l'impact environnemental. Camelina sativa, une culture d'oléagineux flexible au climat avec une faible exigence agronomique, offre des alternatives prometteuses aux huiles dérivées du pétrole. L'huile obtenue à partir de graines de camelina a le potentiel de remplacer le pétrole comme matière première pour la production d'oléochimiques, qui sont des composés dérivés d'huiles végétales ou animales et/ou de matières premières pétrochimiques. La connaissance approfondie du génome de la camelina, associée à l'optimisation du processus pour obtenir des lignées de camelina génétiquement modifiées avec des huiles modifiées à la demande, fait de cette culture oléagineuse un cheval de bataille pour contrer l'impact environnemental dérivé de l'activité humaine.

Mots clés : Biotechnologie / *Camelina sativa* / Environnement / Oléochimique / Soutainabilité

☆ Contribution to the Topical Issue: "Non-Food Uses Of Oil- And Protein- Crops / Usages Non Alimentaires des Oléoprotéagineux".

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Highlight

- The global community is actively seeking solutions to address the climate emergency.
- In the context of greenhouse gases mitigation, plant biotechnology and, specifically, the oilseed crop Camelina sativa.
- Emerge as a powerful tool to provide alternative feedstock to produce oilderived compounds and substitute the non-renewable supplies like petroleum, damping down human activity impact on climate.

Introduction

Climate change is pushing our society to undertake socioeconomic changes to limit the emission of greenhouse effect gases (GHG), which contribute to the increase in global average temperature by retaining solar radiation and ultimately increasing the energy kept by the atmosphere that is not released back to outer space. Although there are compounds like methane (CH_4) with a strong greenhouse effect, carbon dioxide (CO_2) is the major GHG emitted by human activities. In fact, the total amount of CO_2 emitted since the beginning of the industrial revolution has not stopped growing worldwide (CO_2 emissions – Our World in Data, 2024). This is pushing our governments to gradually reduce GHG emissions by driving their national policies towards economic and environmental sustainability. All these transformative measures bare a considerable economic impact on our society (Gillingham and Stock, 2018), making public authorities look for solutions to mitigate human impact on environment without harming productivity. One of these strategies is carbon fixation using rotating crops. The interest on this technique is growing, as it is capable of reducing the amount of CO_2 in the atmosphere and partially fix it to the soil (King and Blesh, 2018). Another good weapon to dampen the economic impact of these transformative changes of society is plant biotechnology. It offers a wide range of possibilities to mitigate GHG emissions from the agricultural and industrial sectors, such as reducing the use of pesticides and enhancing plant tolerance to abiotic stress, resulting in a more efficient production with lower environmental impact (Delangiz *et al.*, 2019). The optimization of crops becomes relevant when it comes to the production of oleochemicals, which are compounds obtained from vegetable and animal oils and fats and/or petrochemical feedstocks. Historically, petroleum served as the primary source of these products, commonly referred to as petrochemicals. Nevertheless, its production had significant environmental implications due to its reliance on a non-sustainable source (Tilsted *et al.*, 2023). At the present time, when sustainability is becoming one of the main priorities for industries, manufacturers are gradually switching from non-renewable sources, such as petroleum, to more sustainable feedstocks, such as plant residues or oils (Grand View Research, 2018), which bare very different applications with a much lower environmental impact.

Concerning the production of oleochemicals from renewable feedstocks, platforms like the oilseed *Camelina sativa* are underway to become one of the major on-demand *green* oil supplies, since its oil can be used for the production of oleochemicals in non-food industries, such as cosmetic products, medical supplies, biofuel, bio-based lubricants or surfactants, cleaning agents, biodiesel (Cerone and Smith, 2021; Scrimgeour *et al.*, 2020). Camelina is a short-cycle, climate-flexible crop, with a low agronomical exigence in terms of irrigation and baring a high seed oil yield (Matteo *et al.*, 2023). This crop, whose genome is deeply characterized, has become a biotechnological platform for the design of new oils through genetic engineering, establishing the bases for the production of camelina as a biofactory for new sustainable compounds (Bansal and Durrett, 2016). The potential of camelina to design new oils proves its ability to become an important tool to reduce GHG emissions and slow down climate change.

In this context, many researchers and companies around the world are advocating camelina as a weapon to combat environmental degradation. Research on camelina became more popular during the last decade, increasing from 8 published articles in 2008 to 173 in 2022 found in the ScienceDirect Web-based repository (ScienceDirect, 2023) (Fig. 1). In addition, public authorities recognize *Camelina sativa* as a strategic crop for energy purposes in Europe and the United States. For example, the European Union invested EUR 7.5 million in a project to revalue *Camelina sativa* oil for the production of herbicides, bioplastics, and animal food (EU Commission, 2022). Furthermore, the US Department of Energy granted USD 12.8 million a project to develop new pennycress and camelina that would allow the development of biofuels to replace petroleum-derived energy sources (UNL, 2023). The growing interest in camelina is also evident within the business sector. Companies such as Syngenta, a global agribusiness company specialized in seeds and crop protection products, have recently reached an agreement with Sustainable Oils to sell camelina seeds for industrial purposes to be used as feedstock for sustainable aviation fuel and renewable fuels (Syngenta, 2023). Further companies such as the Spanish multinational Camelina Company are interested in improving camelina to obtain new oils. This company developed 11 camelina commercial varieties and has an international presence with more than 25 R&D centres, cultivating more than 50,000 hectares dedicated to oil production and the development of new varieties (Camelina Company, 2023). Furthermore, aviation companies, such as United Airlines, are showing interest in oilseeds, such as camelina, to replace airplane fuel with biobased power sources in the future (United Airlines, 2020). Regarding potential food uses, there are some camelina varieties with a high yield of omega-3 fatty acids, with a composition similar to fish oil in docosahexaenoic acid (DHA) and eicosapentaenoic acid 180 (EPA) (Usher *et al.*, 2015). Recently, two companies, Yield10 Bioscience and the BioMar group, reached an agreement for a long-term partnership to develop and commercialize these camelina lines to improve the feeding of the fish farm from environmentally sustainable sources, such as camelina oil (BioMar, 2023).

The interest that camelina is receiving represents an opportunity for sustainable economic growth. The oleochemical market, looking for greener alternatives to be used as a feedstock to offset GHG emissions, can use camelina oil as a substitute for petroleum-derived oil. Regarding market growth prospects, oleochemicals are expected to grow by more than 6% annually, driven by the high demand for

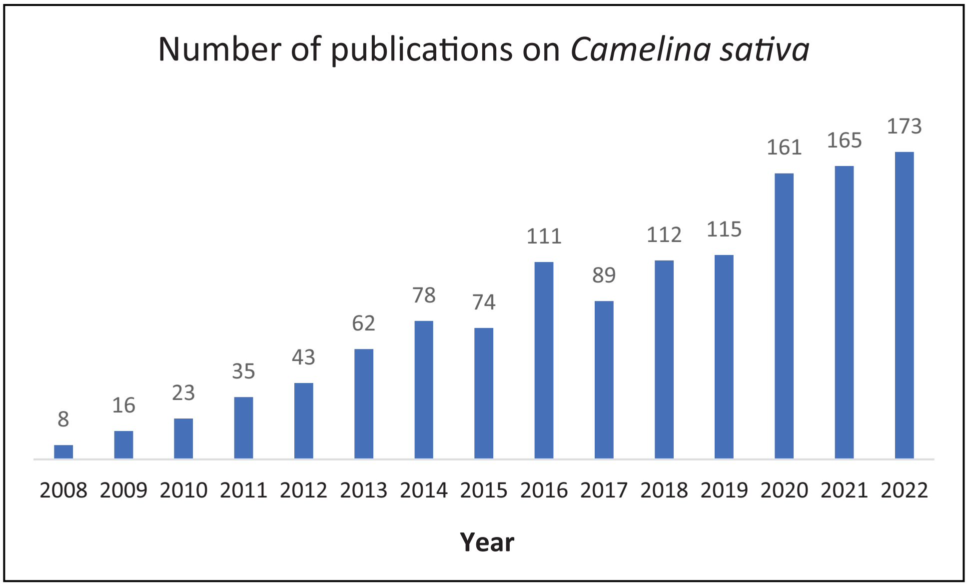

Fig. 1. Number of publications on *Camelina sativa*. Data taken from the science direct search '*Camelina sativa*' (https://www.sciencedirect.com/search?qs=camelina%20sativa).

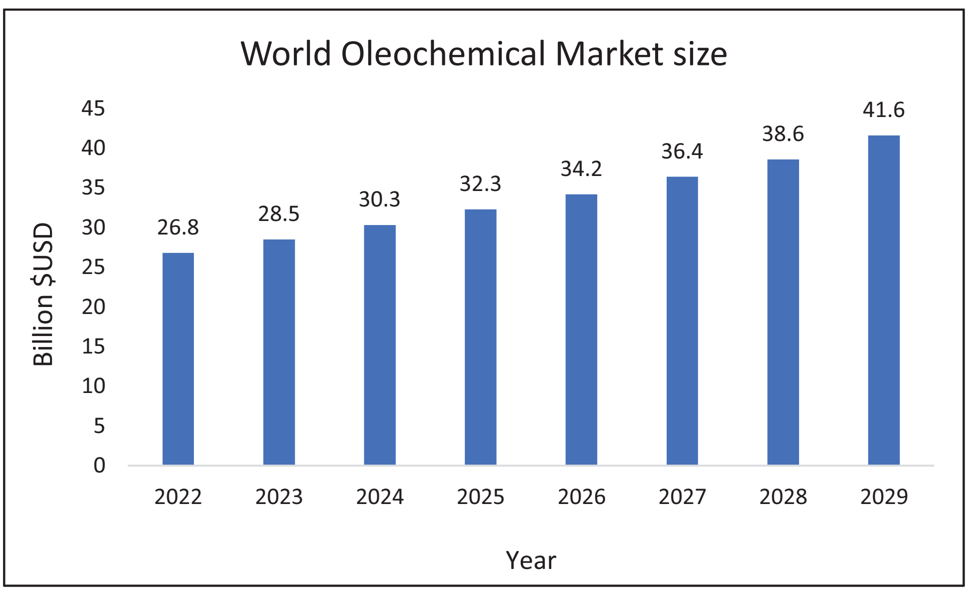

Fig. 2. Estimation of the global oleochemical market size from 2021 to 2029. Data taken from (Transparency Market Research, 2023). The data for 2022 are based on actual figures, while the data from 2023 to 2029 represent a forecast at an estimated annual growth rate of 6.6%.

sustainable oil sources, increasing the economic production of this sector from 26.8 USD Bn in 2021 to 41.6 USD Bn in 2029 (Fig. 2), an expected growth of almost 65% in eight years (Transparency Market Research, 2023). This backs up the use of camelina as a *green* platform for oleochemical production. The oleochemical market is mainly held by the largest economic powers in the world, whose 86% of the total production belongs to Europe, North America, and Asia-Pacific, while the rest of the world produces the compounds derived from the rest of the vegetable oil (Fig. 3), which shows that this crop can be globally useful.

The world is looking for new alternatives to become more sustainable, and these structural transformations are boosting research and business on camelina and other oilseed crops such as pennycress or castor, establishing the basis for a sustainable industry in the coming years.

2 *Camelina sativa*, a platform for on-demand oil production

Camelina sativa is a Brassicaceae plant originally cultured in the Ural Mountains, but it started to become popular in

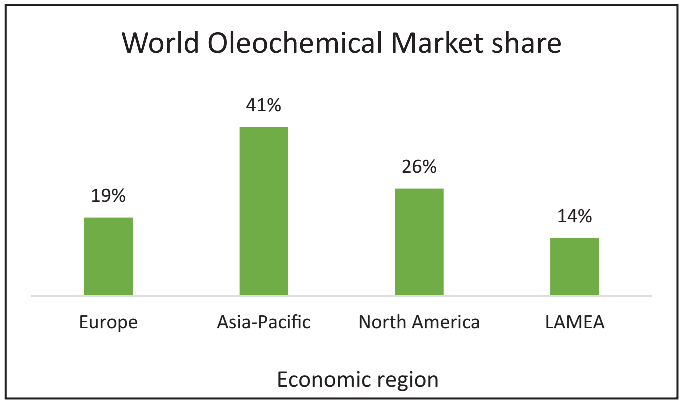

Fig. 3. Global oleochemical market valued at $26.8 billion in 2022 share by economic region. North America (US, Canada, Mexico), Europe (Germany, France, UK, Italy, Spain, Rest of Europe), Asia-Pacific (Thailand, Vietnam, Philippines, Indonesia, Malaysia, Singapore, Japan, South Korea, India, China, Australia, Rest of APAC), LAMEA (Latin America, Middle East) and Africa (Brazil, Argentina, South Africa, Rest of LAMEA). Data taken from (Fortune business insights, 2022).

Europe until the decade of 1940 for industrial applications like lamp fuel or as food supply, as edible oil. After World War II, the crop was replaced by other more productive crops like sunflower or rapeseed, becoming again more popular with the rise of biotechnology in recent times (Francis and Warwick, 2009; Rodríguez-Rodríguez, 2014). *Camelina sativa* is genetically close to the model plant *Arabidopsis thaliana*, sharing sequence homology throughout their genomes, although camelina is genetically more complex. This oilseed crop is allohexaploid, but the diploid inheritance of the characters occurs individually in each of the three subgenomes (Malik *et al.*, 2018). Considering that its genome is fully sequenced and many of its genes characterized (*Camelina sativa* genome assembly NCBI – 2023), many of them by homology with *Arabidopsis thaliana*, the plant becomes a good platform for genomic modification. In this regard, it is specially remarkable that camelina oil enriched in DHA and EPA is used as substitutes for fish oil (Tejera *et al.*, 2016; Usher *et al.*, 2015). Furthermore, on the non-food industrial side, the relatively high oil content of the oil in camelina seeds (30–40% of the dry weight) makes the plant an efficient option for the production of biofuels or biolubricants. However, oil still requires optimization and modifications for those applications, since its main components are linoleic (18:2) and linolenic (18:3) acids, which are more prone to oxidation and less stable than other fatty acids (Francis and Warwick, 2009; Gugel and Falk, 2011).

2.1 Genomic modification of *Camelina sativa*

Considering that each gene has three diploid copies (one within each subgenome), genomic modification of camelina is complex, as directed mutagenesis or silencing of genes must go through simultaneous modification of all copies in the allohexaploid genome. Taking advantage of the genome editing techniques such as CRISPR-Cas9, antisense RNA, and micro RNA-mediated gene knockdown (Sainger *et al.*, 2017), many camelina lines have been genetically engineered to modify their oil composition. Some camelina lines have targeted the three homoeologous genes that encode the same protein through CRISPR-Cas9, obtaining knockout mutants with a very intense phenotype. An example is the total silencing of fatty acid elongase 1 (FAE1) genes, reducing the proportion of very long chain fatty acids (VLCFA) from 22% in wild type to 2% in mutant lines (Ozseyhan *et al.*, 2018). In addition, the possibility of modulating gene expression through partial silencing is also viable. Targeting only some of the homoeologous genes that encode a protein using the CRISPR-Cas9 technique opens the possibility of generating new mutant lines with partially silenced genes, an approach called ‘gene dosage’. This is useful to silence some essential genes involved in metabolic reactions and plant development, whose total silencing could lead to lethality or to obtain intermediate phenotypes with respect to total knockout, as some copies are functional. The creation of a set of combinatorial mutants of fatty acid desaturase 2 (FAD2) in camelina with one, two or three silenced genes is an example to demonstrate that this approach is effective to generate intermediate phenotypes, in this case reducing poly unsaturated fatty acids (PUFA) (Morineau *et al.*, 2017). Another widely extended technique for camelina genomic modification is the use of antisense RNA targeting all homoeologous copies encoding a protein. This technique consists in the expression of an antisense RNA complementary to the messenger RNA (mRNA) to silence. This approach is generally referred to as ‘knockdown’, as the technique is not capable of completely silencing genes. An example is the generation of a high oleic camelina using antisense RNA constructs to reduce the activities of FAD2 and FAE1 (Nguyen *et al.*, 2013) (Fig. 4). Another useful approach to silence genes in camelina is the microRNA (miRNA) approach. The main advantage over antisense RNA previously described is that miRNA is more specific, as the target region in mRNA is shorter (Ozseyhan, *et al.*, 2018). The main application of all these aforementioned genetic engineering techniques is optimization of its oil. Therefore, as industry is seeking alternatives to develop biofuels and biolubricants, the reduction of polyunsaturated 18:2 and 18:3 fatty acids is essential to meet industry demands, which requires the development of varieties with a higher content in more stable monounsaturated fatty acids (Broekhof and Herrendorf, 2016).

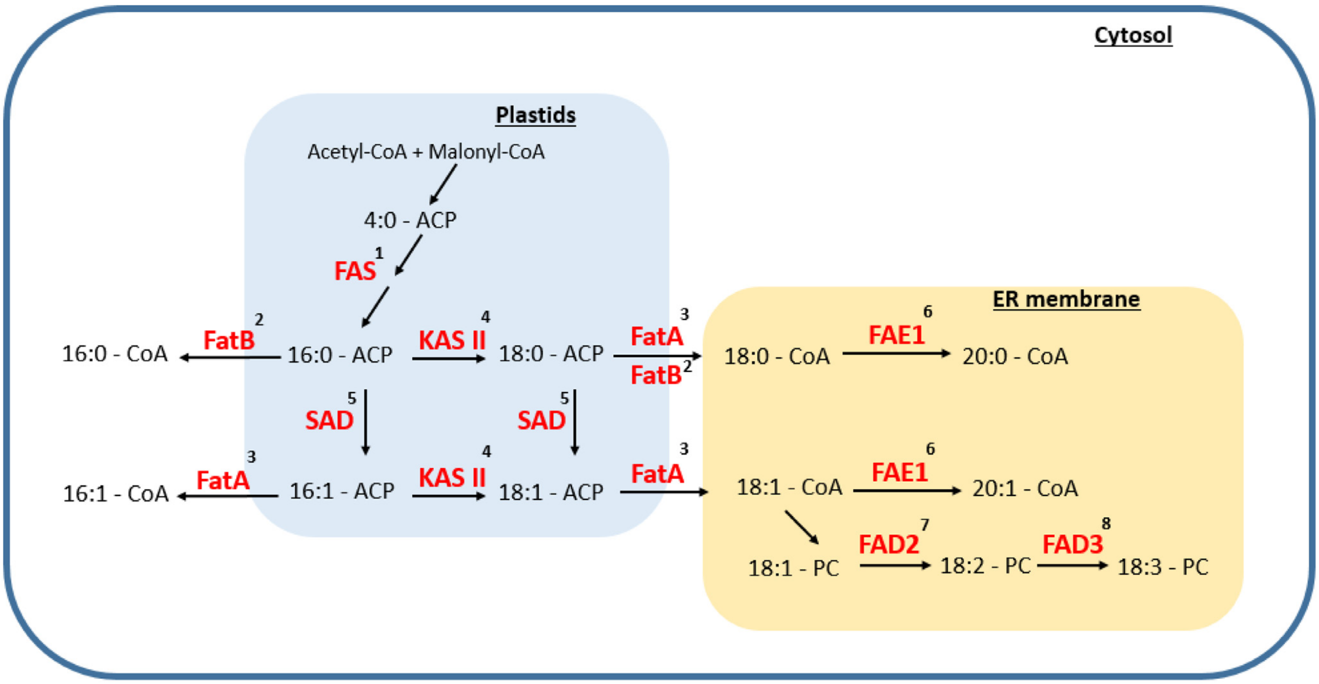

Fig. 4. General scheme of the fatty acid biosynthetic pathway. The main enzymes in the pathway are the FAS complex (Fatty Acid Synthase, [1]), FatA and FatB (Fatty Acid Thioesterases, [2] and [3]), the KASII complex (3-keto-acyl-ACP synthase II, [4]), SAD (stearoyl-ACP desaturase, [5]), the FAE1 complex (Fatty Acid Elongase, [6]) and the reticular FAD2 and FAD3 (Fatty Acid Desaturases, [7] and [8]) (Acyl Lipids: pathways, 2023).

Table 1. Percentage by total oil weight in some genetically engineered *Camelina sativa* lines.

	Standard fatty acid composition, by weight (percentages with respect to the total mass of oil) *Camelina sativa* lines					
Fatty acid (%)	WT[(1)]	High 16:1[(2)]	High 18:1[(3)]	High 18:2[(4)]	High MUFA[(1)]	Low PUFA[(3)]
Palmitic acid (C16:0)	6.80	14.70	7,00	9.40	3.80	5.50
Palmitoleic acid (C16:1)	–	20.30	–	–	–	–
Stearic acid (C18:0)	3.90	2.10	3,20	5.60	2.40	2.90
Oleic acid (C18:1)	11.50	28.00	70.00	22.40	13.40	50.00
Linoleic acid (C18:2)	18.80	9.80	4.00	54.10	18.90	4.50
Linolenic acid (C18:3)	36.40	18.80	10.00	4.80	37.50	13.00
Arachidic acid (C20:0)	3.30	0.56	0.50	1.30	2.80	1.00
Eicosenoic acid (C20:1)	13.00	4.40	2.00	1.80	13.90	18.00
Behenic acid (22:0)	0.50	0.15	–	–	0.40	–
Erucic acid (22:1)	2.80	0.38	–	–	3.50	2.00
Others	3.82	0.81	3.30	0.60	3.40	3.10
Total saturated	14.50	17.51	10.70	16.30	9.40	9.40
Total unsaturated	85.50	82.49	89.70	83.70	90.60	90.60

[1] Ozseyhan *et al.* (2018a).
[2] Rodríguez-Rodríguez (2014).
[3] Nguyen *et al.*, 2013.
[4] Horn *et al.*, 2013.

2.2 Genetic engineering in *Camelina sativa* for improved oil production

Camelina oil is one of the most promising crops for designing, modifying, and mass producing vegetable oils for industrial applications. As shown in Table 1, many stable camelina lines have been generated with modified oils for industrial purposes, such as the development of new biofuels, biolubricants or cosmetics. All the lines described in Table 1 have been generated by genetic engineering modifications of the genes that drive the pathway represented in Figure 4.

2.2.1 High-oleic camelina

Many camelina industrial lines have been genetically engineered to accumulate oleic acid (18:1) by silencing key desaturases and elongases that metabolize it in oil-accumulating seed. According to the biosynthetic pathway represented in Figure 4, the key enzymes to be silenced to generate high oleic lines are reticular FAD2, responsible for the conversion of oleic acid to linoleic acid (18:2) (TAIR FAD2, 2023) and FAE1, whose role is to elongate oleic acid to eicosenoic acid (20:1) (TAIR KCS18, 2023). By suppressing the expression of these two proteins through different techniques such as CRISPR or antisense RNA, some high oleic lines have been developed that accumulate up to 70% of 18:1 within the total oil content (Jiang *et al.*, 2017; Nguyen *et al.*, 2013). In other studies, FAD3 was also suppressed together with FAD2 and FAE1 to generate a very high oleic camelina line with low PUFA (Ozseyhan, *et al.*, 2018). Many of these industrial lines, with an increase in 18:1, are being developed expecting to obtain new platforms to obtain new biolubricants or biofuels, as reducing the content of PUFA and very long chain fatty acids (VLCFAs) increases the stability and improves the physical properties of those oil derived products (Broekhof and Herrendorf, 2016).

2.2.2 High palmitoleic camelina

To increase the content of palmitoleic acid (16:1) in camelina, several genomic modifications were introduced into the genome. By suppressing 3-keto-acyl-ACP synthase II (KASII), the enzymatic complex is responsible for the elongation of palmitic acid (16:0) to stearic acid (18:0) and the overexpression of endogenous camelina stearoyl-ACP desaturase (SAD), an enzyme that catalyzes the desaturation of stearic into oleic acid (*Camelina sativa* SAD NCBI, 2023), Figure 4, lines with up to 24% palmitoleic acid, but still with a high share of PUFA and VLCFA. These lines still require further modifications if they are intended to be used as platforms to make biofuels or biolubricants, but the high thermal stability of palmitoleic acid, together with its low melting point, makes the high 16:1 camelina lines ideal for these purposes, as they have a high share of monounsaturated fatty acids (Nguyen *et al.*, 2015; Rodríguez-Rodríguez *et al.*, 2021; Rodríguez-Rodríguez, 2014).

2.2.3 Low saturated camelina

Another trend for camelina oil optimization is the silencing of the fatty acid thioesterase B (FATB) gene. This enzyme hydrolyzes saturated acyl-ACPs with chain lengths that vary between 8 and 18 carbons (TAIR FATB, 2023), favouring its incorporation into triacylglycerols. This is one of the last steps before terminating fatty acids are exported from the plastids in Figure 4. As FATB acts primarily on palmitoyl-ACP, a reduction in its catalytic activity leads to a lower final content of palmitic acid (16:0), and the final oil composition is modified (Rodríguez-Rodríguez *et al.*, 2014). Some lines of industrial interest were generated by suppressing FATB activity. An example is the effective reduction in saturated fatty acids achieved by the expression of a specific microRNA that targets all FATB genes in camelina. This strategy reduced the saturated acid content by 35%. Furthermore, when silencing was carried out in a high oleic transgenic camelina line, the total oleic acid content was further enhanced (Ozseyhan, *et al.*, 2018). This approach confirmed FATB as a key branch point in the metabolic pathway with potential applications in the generation of industrial camelina lines. More research has been conducted in the field, as more genes have been silenced simultaneously to FATB. This is the case of 3-keto-acyl-ACP synthase II (KAS II), very important for the synthesis of the stearic acid present in the seed (TAIR FAB1, 2023). In this regard, the FATB and KASII genes were silenced using an antisense RNA approach to avoid excessive silencing and prevent a possible lethal effect on transgenic plants. The transformants generated showed a very significant reduction in saturated acid of more than 50% compared to wild-type plants (Nguyen *et al.*, 2015).

2.2.4 High linoleic camelina

Although elevated contents of polyunsaturated fatty acids are undesirable for biofuel and biolubricant production, they are of interest for the formulation of inks, varnishes, and paints (Asif 2011). In this regard, camelina lines with genetic modifications have been generated to accumulate linolenic acid (18:2) in the seeds. For this purpose, fatty acid desaturase 3 (FAD3), whose function is to convert linoleic acid to linolenic acid (18:3), Figure 4 (TAIR FAD3 2023), was silenced together with FAE1 elongase (TAIR KCS18 2023). These biotechnological modifications induce the accumulation of more linoleic acid in the final oil (Horn *et al.*, 2013).

2.2.5 Introduction of new traits to camelina

Several industrial lines have been generated by the expression of key genes of other plant species in camelina to obtain new phenotypes and oil compositions. In this regard, an example of a plant species that has raised interest among researchers around the world is jojoba (*Simmondsia chinensis*). Due to its ability to accumulate straight chain wax esters in its seeds, biomolecules that are highly hydrophobic and resistant to degradation, this crop has many industrial applications (Vanhercke *et al.*, 2013). Many researchers are interested in optimizing the production of jojoba oil in other species like camelina, due to the wider adaptability of camelina to grow under different conditions, its higher oil yield compared to jojoba, and also due to the fact that the camelina genome is more characterized. To transmit all these advantages to camelina for the production of wax esters, endogenous camelina FAD2 was down-regulated through RNAi to reduce

PUFA, and several jojoba enzymes were co-expressed to drive metabolic flux toward the synthesis of wax esters. Driven by the seed-specific glycinin-1 promoter, the FAE1 jojoba gene was co-expressed with wax synthase (WS) and fatty acid reductase (FAR), achieving higher amounts of wax esters (Zhu *et al.*, 2016). Similar strategies were followed, co-expressing in camelina the WS cDNA from jojoba with the *Marinobacter aquaeolei* FAR enzyme, a halophilic bacterium (Huu *et al.*, 1999), which allowed an increase in wax esters at the expense of triacylglycerols (Iven *et al.*, 2016).

Other oils, such as those obtained from castor (*Ricinus communis*) or lesquerella (*Lesquerella fendleri),* are particularly attractive because of the unusual fatty acids they produce, ricinoleic acid and lesquerolic acid, respectively. Various fatty acids with industrial potential can be used in cosmetics, oleochemistry, and lubricant production, as well as in the manufacturing of biodegradable polymers. Therefore, the production of unusual fatty acids with hydroxyl or epoxy groups on camelina platforms for industrial purposes has also raised interest in the industry. Some researchers around the world aimed to generate camelina oils containing hydroxy fatty acids such as lesquerolic acid (Cocuron *et al.*, 2014) or ricinoleic acid (Nitbani *et al.*, 2022). To obtain camelina lines that produce these fatty acids, castor 12-oleate hydroxylase (FAH12) and the 3-ketoacyl-CoA synthase 3 gene (KCS3) from lesquerella were coexpressed in camelina, obtaining a new camelina oil with a higher content of hydroxy fatty acids (Snapp *et al.*, 2014).

2.3 Applications of camelina oil

2.3.1 Biofuels

As society adapts to a more sustainable productive model, there are numerous global efforts underway to reduce the use of fuels derived from petroleum. Camelina oil is a potential feedstock for biofuel production. Concerning its environmental impact, when camelina is planted as a rotating crop, greenhouse gas emissions can be reduced by 40–60% compared to petroleum-derived diesel, but efforts are required to improve the yield of camelina oil and optimize its fatty acid composition (Krohn and Fripp, 2012). High stability and oxidative resistance are also required to produce an oil acceptable for biodiesel manufacturing, but these traits in camelina oil can be achieved through biotechnology to generate high oleic and high palmitoleic lines (Jiang *et al.*, 2017; Nguyen *et al.*, 2013). One of the most common industrial processes to manufacture fuels from plant origins is the so-called triglyceride blend, a mixture of a non-viscous fuel such as gasoline and oil from seeds. In the case of camelina, after 1 year of room-temperature storage, no phase separation was observed, suggesting that triglyceride blends as a biofuel based on camelina oil are viable (Drenth *et al.*, 2015).

2.3.2 Bioplastics

According to the United Nations, by 2050, there will be more plastics than fish in the oceans of the planet. Plastics are present in all environments around the world, and the production of these materials has increased dramatically in recent decades (UN, 2017). Efforts are being made around the world to reduce ocean plastic pollution, from local to national actions (Mathis *et al.*, 2022), but further commitment is required. There is a group of biomolecules naturally produced by bacteria, polyhydroxyalcanoates (PHAs), whose structure and biosynthetic pathways have been deeply characterized. Its industrial interest is based on its ability to form biopolymers and its thermal stability (Behera *et al.*, 2022). Within the PHA molecules, polyhydroxybutyrate (PHB) is found. It was discovered in 1888 and characterized in 1925, as its main function of storing carbon and energy in the bacteria that synthesize the compound. Its physicochemical characteristics make PHB molecules suitable for bioplastic manufacturing, but many logistic and economic failures still require research and optimization (Palmeiro-Sánchez *et al.*, 2022). Economically, more effort is required, as petroleum-derived polymers are still cheaper (Manikandan *et al.*, 2021). At this point, plants acquire relevance. Some approaches have been tested with oilseed crops as platforms to synthesize sources for bioplastic manufacturing, using mostly plant waste to generate products from biomass (Jayakumar *et al.*, 2023). Recently, genetic engineering has led to a deep transformation of industrial futures and camelina has become a workhorse as a productive crop. Although plants do not produce PHB as a compound, recent research has shown that camelina can be used as a source of this bioplastic precursor and help mitigate plastic pollution on our planet. Different seed-specific promoters, such as oleosin or glycinin-1, were tested in camelina to produce PHB, obtaining seeds that accumulate up to 15% of this molecule from the weight of mature seed (Malik *et al.*, 2015). These findings open a new opportunity to change the productive model and make it more sustainable in the coming decades.

2.3.3 Biolubricants

In terms of industrial sustainability, biobased lubricants for machines will play a major role, as there is much ongoing research to switch from mineral oil-based lubricants to biolubricants. Their main function is to reduce friction between surfaces, which is essential for manufacturing industries. The advantage of biolubricants over traditional ones is their biodegradability, but they need to keep the main quality parameters (viscosity, thermal and oxidative stability, or low melting point, among others) for use at the industrial level (McNutt and He, 2016). These properties may be conferred on vegetable oils by their fatty acid composition. In general, monounsaturated fatty acids, such as oleic or palmitoleic acids, contribute to lowering the oil melting point and improving their stability (Erhan and Asadauskas, 2000). Camelina is raising interest as a feedstock for biobased lubricant production, mainly due to its high oil yield per seed and its short life cycle (Almasi *et al.*, 2021), and some industrial lines are being developed with an increased monounsaturated fatty acid content by repressing KASII and overexpressing SAD, causing the plant to reduce the VLCFA content in the final oil. These metabolic changes induced a reduction in the melting point of this oil compared to WT oil (Rodríguez-Rodríguez *et al.*, 2021), which brought this plant closer to being a platform for producing biolubricants, as the final oil becomes more stable for this purpose.

3 Conclusions

Researchers and companies around the world are focusing efforts on the development of new varieties of oilseeds to replace non-renewable energy sources such as petroleum. Biotechnology in oil seed crops plays an important role in optimizing their seed oil composition for industrial purposes such as the development of biofuels, biolubricants, or cosmetics. Among these oilseed crops, *Camelina sativa*, an oil seed crop with low agronomical requirements and with an optimized transformation process, raises particular interest due to the relatively high oil content of its seeds and its short life cycle. With the goal of a sustainable society, the search for greener solutions to maintain the standards of living of a growing global population has become a top priority. In this context, camelina and other oilseed crops have great potential for the promotion of vegetable oils as feedstocks for multiple industrial uses, with biotechnology as a support to broaden the range of use of oilseeds in sustainable industrial activities.

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