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# Oil based cover crops for aviation fuel in Scotland - question and answer report

**July 2025**

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# Contents



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# SRP 25-26 Call down request: Oil based cover crops for aviation fuel in Scotland Q&A

**Tracy Valentine, Shailesh Shrestha & Fiona Burnett**

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## Executive summary

This evidence overview and scoping exercise to determine the suitability of camelina as a crop in Scotland has identified the following summary points, and highlighted priority factors to test if camelina field trials are taken forward in Scotland.

- Research on camelina based in Scotland and even the UK is extremely limited, however there is evidence that it can be grown under Scottish conditions.
- Practical skills and equipment on farm suited to Oil Seed Rape (OSR) production are broadly suitable for camelina production. A review and possible increase in processing capacity to convert seed to bio-oil in Scotland might be required, however.
- Camelina would compete directly with other brassica crops such as oilseed rape (OSR) in Scottish rotations. Pest, weed and disease burdens common to camelina and other brassicas restricts them being grown any closer than one year in four in a rotation.
- Camelina is likely to yield best as a main crop harvested in July/August, compared to earlier harvesting in May as a cover crop to be followed by late sown spring barley. Scottish camelina yields to date have ranged from 0.9 to 2.15 t $ha^{-1}$.
- As a winter drilled main crop, camelina could still perform many of the ecosystem services of a cover crop. Camelina grown as an earlier harvested cover crop will impact on camelina yield and will likely have an impact on the yield of spring barley, if that is grown in the same season after the camelina has been harvested.
- The area of land required to produce the annual requirement of 360k t of oil from camelina is not available within the current arable cultivated land. Several options exist to help remedy this:
  - Assess the potential of including camelina in grazed land as a break-crop.
  - Improve camelina via breeding and enhanced understanding of its agronomy requirements under Scottish conditions to improve both the seed yield on-farm and the % extractable oil concentrating on the requirements for aviation fuel.
  - Explore alternative crops that are less likely to compete with OSR or increase the disease burden e.g. safflower, linseeds instead of, or in-addition to, camelina.
- The area of OSR in Scotland needed to produce 360k t oil is estimated at 230k ha (current OSR 33k ha). This compares to somewhere between 389k –1224k ha for camelina (from scenario modelling of its use as a main crop through to its use as an unfertilised cover crop).
- Current arable land in Scotland totals only 566k ha. Since camelina or OSR could only be grown a maximum of one year in four then total available arable land is only 141k ha per annum (108k if OSR is not displaced). Taking in some temporary grass in fields suited for combinable crop machinery could make more land available but may be undesirable for other reasons. Even taking in all temporary grass (585k ha annually) assuming camelina

cropping 1 year in 4, could only add 146k ha which would still be short of the minimum needed even if the optimal camelina yields in the scenarios modelled was attained.

- Economically, for individual farms, growing camelina or increasing production area under oilseed rape (OSR) may not be economically feasible. Farms will need additional incentives and support to produce camelina or oilseed rape (OSR) as an alternative biofuel crop on farms. Under the scenarios modelled for this call down, the minimum farm gate price for camelina as a main crop would need to be £1328 $t^{-1}$. A comparable figure for OSR would be £622 $t^{-1}$. These are significantly higher than current market prices of £440 and £478 respectively.
- Breeding programmes could help to raise camelina yields. Oil quality in camelina has been manipulated using GMO and GE techniques (and field tested) in England but these would not be suitable for Scotland under the current GM moratorium.
- Maximum camelina yields derived from literature were 3.65 t $ha^{-1}$. This gives some idea of the gains attainable through optimised breeding and agronomy. If achieved this in turn would approximately halve the land area estimates above – but it should be noted that on these figures the land area needed to produce 360k t of bio oil each year would still be greater than the maximum available arable area in Scotland of 141 ha.
- If camelina trials are taken forward in Scotland priority factors for testing include:-
    - Compare alternatives to oilseed rape (OSR), including multiple cultivars of camelina, safflower, linseed and mustard from multiple sources.
    - Seed rates and interactions with weed control and lodging risk
    - Nitrogen and sulphur rates and interactions with weed competitiveness and yield
    - Herbicide trials – crop safety and effectiveness of actives and programmes of actives with a focus on broad leaf weeds and the use of pre-emergence, residual and post emergence actives.
    - Crop safety and effectiveness of insecticides (lower priority)
    - Control of downy mildew and albugo white blister through fungicides (low priority)
    - Impact of combined agronomy on biodiversity and soil.
    - Assessment of factors above on the oil yield and the oil quality profile.
    - Modelling of the yield, cultivar and environment data from available literature may help to optimise the balance between the seed yields and the oil contents to produce the maximum per $ha^{-1}$ oil production level and increase our understanding of the environmental impacts on oil quality.
- It would be useful to consider the work of Leclère et al. 2018 when developing any on-farm trials.

# Introduction

The Scottish Government is committed to tackling climate change with an ambitious target of 2045 for Scotland to reach net zero emissions for all greenhouse gases. As part of this transition new uses need to be found for sites such as the Grangemouth refinery to secure a just transition for the local and wider Scottish population. Project Willow: Grangemouth investment opportunities has identified a set of preferred projects including a proposed biorefinery project for aviation fuel. The aviation sector is currently a significant greenhouse gas emitter through its use of fossil fuels (Okolie et al. 2023) thus key to the success of this option is the production of, and access to, sufficient volumes of feedstocks of bio-oil of appropriate quality with a low climate impact. Project Willow highlighted that there is not enough waste oil to supply this need, therefore, oil-based crops would need to fill this gap in the oil supply chain. This review is in response to a policy call-down project request in the form of a Q&A style report to answer questions on the potential for oil-based cover crops to produce bio-aviation fuel in Scotland. Potential crops include camelina and oilseed rape (OSR), and this report includes a screen for potential alternatives. Also included is the potential of a camelina breeding programme, together with economic analysis of the competition between camelina, OSR and cereals for land.

## 1. Is Camelina an appropriate crop for use as a cover crop producing seed for oil production in Scottish growing conditions?

### Cover crops background

Cover crops can take several forms, they are usually a mixture of species but can be single species crops, grown with the aim of improving or maintaining soil structure and function and improving other ecosystem services (Mohammed et al. 2020). In arable land use, (winter) cover crops are used to protect soil from erosion, and can, depending on species and soil conditions, add carbon and nitrogen to soil (Eberle et al. 2015; Ghidoli et al. 2023), act as a biofumigants (reducing pests and diseases), increase soil water holding capacity (thus reducing flooding and nutrient run off into water bodies), improve pollinator numbers and biodiversity (Thom et al. 2018) and in some cases increase follow on crop yields (Holland et al. 2021). Cover crops can also be left in the ground for a whole season but then are more often referred to as fallow. Winter cover crops are usually sown in the late summer / early autumn in the northern hemisphere as soon as practically possible after the previous crop has been harvested and, if necessary, soil management undertaken. Timing is of particular importance in northern / colder climates to ensure enough canopy growth for the cover crop to perform soil protection functions. Cover crops in Scotland also ideally need to be low light and cold tolerant. Cover crops are not usually grown for a seed yield; they are usually destroyed or cut with the biomass incorporated into soil or left as a mulch around March prior to spring sown cropping.

### Camelina and Camelina as an oil seed producing cover crop

Camelina (*Camelina sativa* L Crantz) is an oilseed crop from the Brassicaceae family. It is considered a multi-use crop with evidence that it has been grown in Europe as far back as the bronze age (Reed et al. 2024) with potential uses in the human food chain from edible oil to emulsifiers (Lopez et al. 2024), as fuel e.g. diesel (Drenth et al. 2015) and has also been used to produce aviation fuel which has been tested in jet aircraft engines (Zhang et al. 2012). Camelina and particularly winter camelina offers potential to grow feed stocks in multiple environments across Europe and USA (Walia et al. 2021). It has been grown in a wide variety of conditions across the northern hemisphere including, Romania (Podgoreanu et al. 2015), Canada (Gugel and Falk 2006; Jiang et al. 2014), Ukraine (HryhorivYa et al. 2022), USA (Gesch et al. 2014; Liu et

al. 2019), Germany (Groeneveld and Klein 2014) and across Europe and Africa (Berzuini et al. 2024). Camelina can be grown as both a traditional winter crop (Berti et al. 2017; Gesch et al. 2021) replacing some of the functions of cover crops or as a spring crop sown in April/May (Bujnovský et al. 2020; Codina-Pascual et al. 2024).
Trials in the UK using camelina have been very limited. Pearson and Walker 1999 includes field trials in Scotland and England and trials of genetically modified camelina have been performed under Ministerial consent in England (Usher et al. 2015; Han et al. 2022). The Pearson and Walker 1999 trials tested both spring and winter cultivars of camelina using different planting densities (600-1000 seeds per $m^2$) and a range of applied nitrogen (N) rates (70-130 kg N $ha^{-1}$). Seed was harvested from the trials with the winter mean yields ranging from approx. 0.9 to 2.3 t $ha^{-1}$ depending on season. Yields from optimal treatments were slightly higher and ranged from 1.1 – 2.8 t $ha^{-1}$. They also tested sulphur (S) as an addition but were unable to conclude on the benefits. It is therefore possible to grow camelina in Scotland over winter (effectively as a cover crop) and harvest a yield. Harvest dates are not given in the publication but are believed to be July / August (pers. Comms. Lawrence Greig, SAC trials officer). They used a range of cultivars and concluded that they exhibited a range of agronomic traits. They also concluded that camelina could be successfully grown in the UK without the introduction of new skills. Camelina could be frost vulnerable in the first 10 days, but this was only evidenced from one sowing in one year. They stated lodging can be a problem at very high seeding rates. The impact of weeds and disease on yields, and volunteer control in wet areas were considered potential issues.

## 2. If not, are there any other suitable alternative oil producing crops that should be considered?

While camelina is suitable to grow in the Scottish climate, its competition with OSR due to pest, disease and weed pressure (see below) means alternatives might also need to be sought. These need to be suitable for the Scottish climate, produce an appropriate quantity and quality of oil. Blackshaw et al. 2011 & Tao et al. 2017 suggested 9 & 20 alternative oil feedstocks (respectively) for potential use in the jet fuels renewable supply chain. Of those reported, rapeseed/canola, pennycress, mayflower, mustard and linseed are possible alternatives to camelina in Scotland (Table 1). Sunflower was also mentioned but is less likely to reliably seed in Scotland. Only camelina and pennycress were fully economically evaluated with the conclusion that pennycress could also serve as a feed stock for biofuels however it has a significant percentage of $C_{20}$ therefore an extra process (Hydrocracking) is likely be needed for improved jet fuel production (Tao et al. 2017).

Mustard oilseeds are already grown in Scotland as a traditional over wintering cover crop and for seed for human and animal consumption. Linseed is also grown for use as edible seeds, oil, and fibre and is part of the Linaceae family. A small flax mill renovation is due to open in Fife in 2026 (https://www.silverburnpark.co.uk/flaxmill) for fibre production and community use so there maybe opportunity for co-production depending on the processes involved, albeit on a very small scale. Safflower can be used for natural dying and comes in two types; those high in monounsaturated fatty acid (oleic) and those high in polyunsaturated fatty acid (linoleic) (https://www.yara.co.uk/crop-nutrition/novel-crops/safflower/). As it is part of the Asteraceae family it may offer an alternative to plants from the Brassicaceae. It is salt, drought and heat tolerant (Hunsaker et al. 2011; Hergert et al. 2016; Hussain et al. 2016) and is hardy to -10 to-15°C (https://www.rhs.org.uk/plants/28835/carthamus-tinctorius/details). Research has also highlighted the potential of using Safflower Oil as a feed source for aviation fuel (Tepelus et al. 2022).

| Table 1 : - Alternative to Camelina for use as a cover crop for producing oil | | | | | | |
|---|---|---|---|---|---|---|
| **Edited from (Tao et al. 2017; Mitrović et al. 2020; Nykter et al. 2006)** | **Alternative names** | **Seasons** | **Food usage** | **Group** | **Oil content** | **Other comments** |
| Camelina (Camelina sativa) | False flax Gold-of-pleasure | Winter / Spring | Yes | Brassicaceae | 35% High in omega-3 fatty acids | Drought tolerant / water use efficient (yield vs. evapotranspiration) compared to other oilseed crops |
| Rapeseed/Canola (Brassica napus / Brassica napus cultivar) | | Winter / Spring | Yes | Brassicaceae | 38-45% | Moderate tolerance to soil salinity, moderately drought tolerant |
| Pennycress (Thlaspi arvense) | Stinkweed French-weed | Winter annual, Followed by another crop | No | Brassicaceae | Up to 36% Oil | Tolerant, requires minimal inputs (fertiliser, pesticides, water). Non-food crop limited but some breeding. |
| Safflower (Carthamus tinctorius) | False saffron | Winter annual | No | Asteracea | 23.08% to 36.51% | Heat, salt and drought tolerant |
| Mustard (Brassica juncea) | mustard greens, brown mustard, | Winter/ Summer annual | Yes | Brassicaceae | 21% to 43.5% | Currently grown in Scotland |
| Linseeds (Linum usitatissimum) | Flax, Common flax | Winter / Spring | | Linaceae | 26–45% | Currently grown in Scotland |

## 3. What are the requirements for land use needed to produce 360K tonnes per annum of oil.

The total Scottish agricultural area in 2024 was 5.16 million hectares (excluding rough grazing), equalling 66% of Scotland's total land area. According to Gueye 2022 Scotland's agricultural land capability consists of:- Arable agriculture – land capable of being used to produce a wide range of crops = 8% of Scotland's total land area; Improved grassland – land limited to grass production due to circumstance such as sloped = 18% of Scotland's total land area; Mixed agriculture – land able to produce a moderate range of crops including cereals (primarily barley), forage crops and grass = 20% of Scotland's total land area; Rough grazing – land with very severe limitations that prevent improvement by mechanical means = 51% of Scotland's total land area. Camelina is considered as a crop that can be grown on marginal land (McKenzie et al. 2011; Zanetti et al. 2024), including as a break crop in pasture land. Thus, it could potentially be grown in areas not suitable for other cropping. This would equate to it being suitable for growing on high quality agricultural land through to some types of grazing land as a break-crop (Class 1 through to Class 4.2). In the economic analysis below only cereal/arable farms are included. However, camelina would only be able to be grown a maximum of one season in four due to pest, weed and particularly disease pressure (see below) and would compete with OSR. This would be the same for all the other Brassicaceae alternatives. The option of using it as a break-crop within grazing land has not been explored in the UK. Safflower and linseed would not compete directly with OSR, but further research would be required on the land requirements for safflower. Linseed is currently grown as a minor crop.

## 4. What would be the expected yield per hectare and how many hectares would be needed to produce 360k tonnes per annum of oil?

The following calculations are based purely on camelina. In Pearson and Walker 1999 Camelina was grown in both Scotland and England, with successful crops grown with 100 kg N ha$^{-1}$. Trials were sown in both spring and autumn. Mean yields in the Scottish trial varied from ~0.9 t ha$^{-1}$ to ~ 1.95 t ha$^{-1}$ for the spring sown trials and 0.9 – 2.15 t ha$^{-1}$ for the winter sown trials. In Canadian trials Jiang et al. 2013 found the maximum yield achieved across all treatments and years was ~ 2.4 t ha$^{-1}$ for spring sown and 2.8 t ha$^{-1}$ for autumn sown camelina. There was significant variation between years and locations. Yields of up to 3.65 t ha$^{-1}$ have been achieved in winter sown camelina in other systems e.g. Croatia (Czarnik et al. 2018). Similarly, Jiang et al. 2013 found N increased seed yield, protein content and yield and % polyunsaturated fatty acids, but N reduced the oil content and reduced the monosaturated fatty acids. Optimum N for yield ranged from 120 to 160 kg N ha$^{-1}$. Sulphur impacted yield, protein and oil components only when N was sufficient. Oil content generally ranged from 33 – 39%, however one study showed that in some cultivars oil content could be increased to 44% (Zubr 2003). Table 2 shows the area required assuming yield was in the region of the Scottish trials low (0.9 t ha$^{-1}$, Pearson and Walker 1999), medium (2.1 t ha$^{-1}$ also achieved in the Pearson and Walker 1999 trial) and high 3.65 t ha$^{-1}$ (Czarnik et al. 2018).

**Table 2 : Land area required to produce 360k tonnes of oil per annum based on typical crop yields and oil extraction yields - Calculated as Required Oil * (100 / % Oil yield ) / Yield (t ha-1)**

| Oil yield | Amount of seed yield required (tonnes) | Required land based on yield (t ha-1) - ha/annum | | |
|---|---|---|---|---|
| | | low 0.9 t ha$^{-1}$ | medium 2.1t ha$^{-1}$ | high 3.65 t ha$^{-1}$ |
| **32.67 %** | 1101k | 1224k | 524k | 302k |
| **39 %** | 923k | 1026k | 440k | 253k |
| **44 %** | 818k | 909k | 389k | 224 k |
| **Intercropping** | | **0.62 t ha-1** | | |
| **44 %** | 818k | 1320 k | | |
| **Oilseed rape (OSR)** | | **3.9 t ha$^{-1}$** | Ten year OSR yield | |
| **40%** | 900k | 230k | | |

Currently it is estimated that approximately 566k hectares in Scotland are cropped for cereals, combinable crops, fruit and vegetables in Scotland (Affairs 2019). Due to disease pressure the advice would be to only grow OSR or camelina a maximum of once in every 4 years. This reduces available land to a maximum of 141 k ha in any given year that could be set aside for brassica growing (either OSR or camelina; vegetable and other brassica crops have been ignored for this purpose). Currently approximately 33,000 ha are being used for OSR each year, so there is the potential to use up to 108k hectares for camelina grown as cover crop. As can be seen from the table above, this would require a significant increase in both the extractable % oil, and the yield per hectare to achieve. As illustrations, even if the extractable oil was increased to 50% by breeding and appropriate agronomy then to produce 360k tonnes of oil, 720k tonnes of seed would be needed. If all the available "Brassica" land was used for camelina oil (141k ha) the yield per ha would need to be in the region of 5.1 t ha$^{-1}$ which would have to be achieved through breeding higher yielding more disease resistant cultivars. For comparison the current ten year Scotland average for OSR yield is 3.9 t ha$^{-1}$.

## 5. When would the crop need to be planted and harvested as a cover crop?

If grown as a winter (cover) crop it would need to be drilled Aug /Sept and grown for a longer period than traditional cover crops (which are usually destroyed around March) as it would need to be grown to seed, with potential impact on the follow-on crop. Winter camelina is usually harvested from May-Aug although harvests have been published as late as September (Walia et al. 2021; Zanetti et al. 2024). Growing degree days (GDD) for camelina is approximately ~1261- 1758 ºC (Walia et al. 2021; Berzuini et al. 2024) but at the upper range of time to flowering, yields can be increased by as much as 1.5 fold (Berzuini et al. 2024).

## 6. Could these crops fit into a rotation, without the need to remove a main crop, while producing harvestable oil seed? If so how (cover crop, relay crop, intercrop) and how could this work in practice?

Camelina has been grown over winter as a cover crop usually harvesting in from May to Aug (Walia et al. 2021) depending on location and cultivar. This is later than normal spring barley sowing dates, but if an early (May) harvest is achieved, it might theoretically be possible to sow a following spring crop however, there would be a yield penalty (possibly as high as 1.9 t $ha^{-1}$) to late sowing of the spring barley (Cammarano et al. 2019) and there may also be a yield penalty for the camelina (Berzuini et al. 2024). Safflower, like camelina, can be sown in spring or autumn, but current cultivars mature later in the season and so current cultivars are likely to compete more directly with current crop choices. Alternative options include growing camelina as an intercrop with either a legume or with cereals, and/or as spring crop. Evidence from intercropping research has shown a mixture of results when camelina was intercropping with spring barley (Reuter et al. 2022). Reuter et al. 2022 showed spring barley yields were either slightly reduced or unaffected by intercropping but did not report camelina yields, whereas Pagani et al. 2024, evaluating both spring and winter intercropping, showed a negative effect on camelina, but no effect on the peas it was intercropped along-side. Leclere et al. 2021 found reduced yields for both camelina and barley when intercropped although they did not calculate the land equivalent ratios, and again these were spring rather than winter sowings.

The impact of the following options on the economics of the rotations has been considered below: assuming camelina can be grown as a cover crop, harvested early in May, with a crop such as a short season spring barley sown after it, thus allowing double cropping with minimal effect on the barley production (potential 0.5 t $ha^{-1}$ reduction in yield - note that losses could be much higher at 1.9 t $ha^{-1}$ ). See economic analysis of scenarios below; S1 with fertiliser; S2 without fertiliser; S3 would involve the intercropping of camelina with other currently produced crops, this could include winter or spring barley or peas; S4 would require camelina to be grown as the main crop. Assuming the current level of OSR is grown for other uses, it is likely that this would require to be replaced by camelina. In the economic analysis below, we have also compared these with an expansion of OSR to fulfil the aviation feedstock need.

## 7. What is known about growing oil based crops as cover crops on an international basis (focussing on areas with a similar climate)?

Camelina has mainly been used in the USA as a cover crop, and as an over wintering crop in trials across Europe and Canada. Seed quality traits are highly variable and environmentally dependent (Zubr and Matthäus 2002; Walia et al. 2021). In Walia et al. 2021 (Poland, Italy, Greece, Canada, USA, and Spain), environments with a short growing cycle and high temperatures depressed seed oil content. Thousand kernal weight, seed oil content, linolenic acid (C18:3) content, and omega-3/omega-6 FA ratio (n-3/n-6) were promoted when grown in environments with prolonged growing seasons and evenly distributed precipitation. Due to strong variation in the environment's impact on seed quality Walia et al. 2021 suggested growing conditions should be carefully considered when considering large scale growing of camelina, based on one genotype grown across 6 different locations in north American continent and EU. Based on annual precipitation totals, Scotland records higher precipitation but similar mean temperature across the areas studied. Similarly, Zubr and Matthäus 2002 found variation in oil quality profiles from samples from Denmark, Germany and Sweden. In addition, although camelina is relatively tolerant of stress, high temperature stress, drought stress, salinity stress and water logging stress can occur (Abbas et al. 2021). Drought stress should be a consideration going forward even in Scotland, as the recent period of early spring drought would coincide with seed development.

Mohammed et al. 2020 used broadcasting methods to compare camelina as a cover crop with pennycress & rye sown into soybean and maize in the Mid-West. Winter rye was the highest % cover in 3 out of the 4 sites, but pennycress had a high biomass cover of 40%, compared with rye (30%) and camelina (20%), so soil cover needs to be considered if camelina was to replace some of the potential cover cropping in Scotland. They also suggested that pennycress was a strong cover crop for Northern latitudes. No impacts on yield or soil water were found in this study. Weyers et al. 2019 also compared pennycress and winter camelina; both acted as good N sinks in spring, and reduced $NO_3^{-}$N in soil water during the cover crop phases. This supports the potential of pennycress as a potential alternative to camelina.

Gesch et al. 2021 also investigated the use of camelina in the Upper mid-west of the USA, where short growing seasons mean the establishment of winter cover crops can be challenging, similar to some areas of Scotland. They used a desiccant to speed up the harvesting process of corn prior to direct drilling of the camelina cover crop and this improved establishment of the camelina, highlighting the potential issue of getting sowing dates in the later summer and Autumn optimised.

Camelina exhibits a strong allelopathic affect so is often grown without herbicides (Lovett and Duffield 1981; Hunsaker et al. 2011), it has also been suggested to be naturally antifungal. This can be of particular interest in intercropping situations, where mixed cropping of peas and camelina, can have a suppressive effect on weed coverage compared with mono-cropped peas in the early establishment phases (Saucke and Ackermann 2006) and within winter cover crops (Bekuzarova et al. 2020). Camelina has also been developed for weed suppression in integrated systems (Chao et al. 2023), with a specific cultivar of camelina suppressing weed dry matter by >90% compared with fallow treatments. This suggests that there are important differences between cultivars in their weed suppression and this maybe a potential breeding target alongside (Oil) yield and quality components. Note however that the Scottish trials (Pearson and Walker 1999) specifically mention weed pressure as an issue and required the use of herbicides to maximise yields.

Interseeding (or co-cropping) of Camelina has also been tested. Patel et al. 2021 interseeded pennycress and winter camelina into soybean and corn resulting in greater oilseed yield, but reduced yields of soybean and corn by 13-32% and 13-42%. Sigdel et al. 2021 also interseeded camelina in between sugar beets. Early interseeded cover crops produced three times the biomass of later sowings with winter camelina being the lowest, below mustard and rye. There was no negative impact on yields on the sugar beet.

Other attributes of camelina of interest in the transition of Scottish agriculture to reduced tillage and sustainable systems include Jabro et al. 2021 showing camelina was able to reduce compaction. Chao et al. 2023 also selected freeze tolerance in camelina under No-till systems, suggesting that improvement can be made in these systems by selective breeding. Finally in terms of alternative agronomy Kumar et al. 2012 used a growth inhibitor (paclobutrazol) while growing camelina over winter. The optimised dose achieved higher yields and oil yield (by

15.41%). This may be a route to reduction in lodging risks. Understanding of the mode of action of these growth inhibitors, may also lead to potential breeding targets.

## 8. How does the use of oil based cover crops relate to the food crop land use needs and wider food security (and also energy security issues if there's any evidence).

8 % of Scotland is capable of producing a wide range of crops, 18% is limited to grass production, 20% is suitable for mixed agriculture, and 51 % is only suitable for rough grazing (Gueye 2022). Scotland's food security relies on both the primary production of food crops such as carrots, cabbage and other vegetables (21.5 kha of outdoor vegetables 2023), secondary usage such as winter wheat for feed for the livestock industry and aquaculture industry (107kha 2023) or secondary uses such as spring barley and wheat in the distilling industry (Duffy et al. 2023; Rathnayaka et al. 2024). This latter usage is an important part of the Scottish economy generating food security through the ability to buy imports of food through a robust economy and through the use of waste products as animal feed (Duffy et al. 2023). An overview of Scotland's self-sufficiency of major food commodities suggested that for many commodities Scotland is a net exporter (Rathnayaka et al. 2024). Therefore, the amount of land required to produce the volume of oil feedstock needed means that it is likely that it will need to be grown on both high quality land as well as marginal land (Zanetti et al. 2024). This would potentially impact all areas of land that currently grow oil seed rape and Brassicaceae vegetables (due to the potential of overlapping pest pressures). As part of the Brassicaceae family if land is maximised to grow camelina this will impact on the ability to grow specific food groups (e.g. cabbages, broccoli etc) due to overlapping pests and diseases (see below), so it may be necessary to implement (land) protection measures for areas where these foods are currently being cropped. It would also impact on the areas of land currently under cereals potentially impacting animal feedstocks and the brewing and distilling industry (due to spatial restrictions), as the Brassicaceae crops are not currently grown on all land available every four years, unless Camelina can be grown over the winter without impinging on the sowing dates of spring crops (which is unlikely with current cultivars). However, the extraction of oil from Camelina also produces a secondary pulp protein product which there is evidence can be used as a feed for livestock (Delver and Smith 2024), so it may be possible to replace some of the displaced cereal product used by the livestock industry with Camelina protein. There would however be some processing and/or cultivar development research required to make the meal more palatable. Growing oil-based cover crops over winter would also reduce the impact on spring sown cereal crops but this would require (development of) early maturity cultivars of Camelina and short cycle spring barley lines such as Bere (Martin et al. 2025). Impacts are still likely however as sowing of spring crops may need to occur later than currently performed. Camelina and many of the alternatives are, or can be, used for food oil as well as having potential for producing alternative products (Nykter et al. 2006; Bilska et al. 2024). Camelina oil is high in omega-3 fatty acids (perceived to have health benefits) so using it as a feedstock for aviation fuel may therefore directly compete with its use in food (Tao et al. 2017). Camelina has also been genetically engineered to have increased omega-3 oils. This high omega camelina was transformed into fish food which improved the nutritional value of fish for the human food chain (Napier and Betancor 2023). The ease of transforming camelina means that there are likely to be other genetically edited or transformed camelina developed for other food uses. While currently Scotland has a moratorium on growing genetically modified or engineered plants in the field, should this change then these plants would compete with "Aviation" camelina in the rotation. In terms of energy security considerations, these include climate change impacts on agriculture and the reliance on an agricultural product for aviation fuel with the potential impacts of commodity speculation on price and availability. Although wide spread growing of

Camelina could also be a viable alternative diesel fuels on farm (Bernardo et al. 2003; Keske et al. 2013), assisting in the transition of agriculture as a whole away from fossil fuels.

## 9. What are the barriers to growing oilseed rape as a cover crop instead?

From the evidence gathered above and below, there are likely to be similar issues with growing OSR over winter with regards to amount of land required, although at current yields, OSR will require less land over winter than camelina. Pest, disease and weed burdens limit OSR to being grown a maximum of one in four years. A direct comparison between camelina and OSR (in terms of marginal land capacity) was not found in the literature, however, camelina appears to be more tolerant of marginal land. The main issue with growing OSR as a cover crop is the lateness of the seed maturity which means it would not be possible to follow it with a short season spring crop in the same season which might be marginally possible with camelina. Typical camelina harvest appears to be around May-Aug, with growing degree days (GDD) estimated to range from 1261-1758 °C (Walia et al. 2021; Berzuini et al. 2024). Winter OSR is typically harvested July / August with a GDD estimate of 2728-2749 °C (Hennessy and Donovan 2007; Papantoniou et al. 2013). Critical to understanding the balance between OSR and camelina, will be a direct comparison and analysis of the GDD to each stage of development, as the balance between growth over winter, length of flowering stage and length of seed filling in Scottish conditions is critical to understanding the projected yield across Scotland and camelina's fit within rotations. Note however that when OSR is grown conventionally as a winter crop it fulfils many of the ecosystem services considered advantageous in a cover crop.

## 10. Would it make more sense to use main crop oilseed rape in biofuels, if the amount of land displaced would make this a more land-sparing, food security supporting option?

The amount of land displaced by OSR vs camelina to produce the quantity of oil required based on current yields would be the maximum available in Scottish cropping systems to grow Brassicaceae, i.e. one in four of all arable land available per annum. At current yields, this makes OSR the more efficient option if the oil quality is suitable. If over wintering camelina was successful, following it with spring barley (or other fast-growing crop), might reduce the amount of land displacement relative to a winter or spring OSR due to OSR's later harvest dates compared with camelina (based on GDD). However, there would be significant yield penalties to such a later drilled spring crop and, for practical reasons, opportunities to get a following spring barley crop in after an early camelina harvest might often be very limited. There is the potential to grow camelina as a break-crop in pasture-land, increasing the available land to grow camelina, but this would reduce the grazing availability in those years and may not be preferable, especially as pasture can be regarded favourably for carbon storage and biodiversity gains, and its use for bio-oil production would in itself displace meat production.

## 11. How much main crop oil seed rape would be needed to produce the 360k tonnes per annum of oil.

Based on the ten year Scotland average OSR yield of 3.9 t $ha^{-1}$, and OSR typically yielding around 40% oil, it would take 230k ha to produce 360k tonnes of oil per annum. This is less than the area calculated for camelina which ranges from 389k to 1224k on currently likely yield and oil content ranges (see Table 2) due to the lower camelina yields.

## 12. Are there any consequences on current crops and the environment that should be considered in any future work?

Some previous environmental impact assessments have been made in other environments (Bacenetti et al. 2017). Camelina has been grown specifically as a cover crop with alleleopahic benefits (Ghidoli et al. 2023), and for providing benefits for pollinators (Eberle et al. 2015; Pessereau et al. 2025; Pessereau et al. 2025), however this is in contrast to the findings of (Thom et al. 2018) who found little pollen production in camelina. Spring camelina has been shown to extract water at shallower depths than OSR (Hergert et al. 2016). The potential for camelina to become a long-term part of the seed bank should also be considered. In tests, viable seed persisted less than 15 months at all depths, sites, and years with collected seeds nearly extinct after 2 yr under conventional production practices (Walsh et al. 2013). There is limited evidence of the overall impact of camelina on soils however Blakney et al. 2022 showed camelina host plants had structured phylogenetically distinct bacterial communities compared to the other hosts plants tested, particularly in their roots. Growing camelina one year in four years would reduce the opportunity in those years to have a diverse cover crop, unless distinct underplanting of camelina could be optimised e.g. growing short clover types along-side the camelina (Chapagain et al. 2020).

## 13. What technical harvesting, processing capacity and resource availability is already available in Scotland to produce oil from these crops, if these are not available what would be needed?

Cultivation, drilling and harvest should not require any different farm equipment from those currently used for OSR or other arable crops (Martinez et al. 2020 Stefanoni et al. 2021). However, the plants can cause issues with combines due to the fibrous nature of camelina stems (personal communication arising from 1995 Pearson and Walker 1999 trials). There are two main options for processing the seed into oil and meal. Either the seed is processed locally and the oil sold to the refinery for further processing, or a crushing plant is set up within the refinery linked directly to the production of fuel oil. An economic evaluation of biodiesel production from OSR grown in the North and East of Scotland was produced in 2005. The review details a plant "Seed Crushers Scotland Ltd" that failed, due to inefficiency of the extraction method used, the plant being too small, aggressive pricing by two multinationals (ADM and Cargill), distance of movement from the crushing plant to the storage site, and particularly relevant to this report there was at the time no refining site available at the site so the oil had to be sold to one of the competitors for refining. Issues of contamination of the protein meal, meant that any resource needs to also have the facilities to store this appropriately. ADM & Cargill are still in the business of oil extraction, using extraction plants in England, with diverse portfolios extracting from soybean, corn, sunflower, OSR. There are multiple produces of edible oil for example e.g. borderfields but it is not always clear where their oil is being crushed. Other such as mackintoshofglendaveny, or-ganic and Cullisse, specifically state they crush their own oils. Whether any of these would be interested in expanding their business to also crush seeds for biofuel use would need to be explored. They may also have issues of potential contamination of their products by camelina if the same crush equipment was used. In 2015 the Scottish farmer reported on a new OSR crushing plant being built at South Blackbog, Oldmeldrum, Aberdeenshire by Norvite (to produce oil and livestock feed), stating that Scotland's last such press in Glasgow had closed many years ago. This plant is capable of crushing 4k tonnes of OSR annually producing about 2.6k tonnes of protein-rich meal and 1.4k tonnes of oil, although there is also the capability of expansion.

## 14. How would the economics of growing oil crops for bio-aviation fuel stack up, what price points make it's it a viable option for farmers?

In terms of economic value, the inputs include land preparation, including tillage, herbicides, pesticides, growth control, harvesting costs. Farm gate value will be affected by overall yields, extractable oil (and oil quality) as well as the value of the pulp. A farm level optimising model, ScotFarm (Shrestha, 2020) was used to determine the economic impacts of growing camelina on cereal farms. Four alternative scenarios using different options to grow camelina (as discussed above) and one additional scenario (increasing OSR area on cereal farms) were examined. The production and economic parameters used under each of the scenarios are presented below (Table 3).

**Table 3: Economic evaluation scenarios**

| Scenario | Description | Crop yield (t/ha) | Variable costs (£/ha)[1] | Farm gate price (£/t) | Impact on cereal yields | Potential crop area[3] |
|---|---|---|---|---|---|---|
| S1 | Cover crop (with fertiliser) | 2.5 | 267 | 440[2] | -0.5 t/ha | 19% |
| S2 | Cover crop (without fertiliser) | 1.15 | 123 | | | |
| S3 | Intercropping | 0.4 | 267 | | 1.8 t/ha[4] | 50% |
| S4 | Main crop | 2.5 | 267 | | -25% | 19% |
| S5[5] | Oilseed rape (OSR) | 4 | 489 | 478 | -25% | 25% |

[1] Based on OSR variable costs (FMH, 2023)
[2] Adopted from the Canadian camelina price range of $562 to $661 per tonne
[3] Percentage of total farm area under cereal
[4] Yield loss for spring barley
[5] All the figures in S5 scenario are for OSR

The economic impact under each of the alternative scenarios on an average arable farm is shown in Figure 1. The farm incurs economic loss under all alternative scenarios. Camelina included as a main crop scenario is estimated to have the highest loss (£51,554) on the farm (see Figure 1). Camelina used as a cover crop especially without the use of fertiliser show the lowest loss to the farm. An increase in OSR area is also estimated to have a £22,294 annual loss to the farm at current prices. Based on economic losses to the farm under the alternative scenarios, we estimated the market price for camelina (and OSR under S5) that can cover the loss under each scenario (Table 4). This estimated price included the market price (£440 $t^{-1}$ price for camelina and £478$t^{-1}$ for OSR) and opportunity costs of reallocating land under camelina (and OSR under S5) in each scenario. This shows that at optimal camelina yields grown as a main crop, the price for camelina would have to be £1328 $t^{-1}$ to break even. A comparable figure for OSR would be £622 $t^{-1}$.

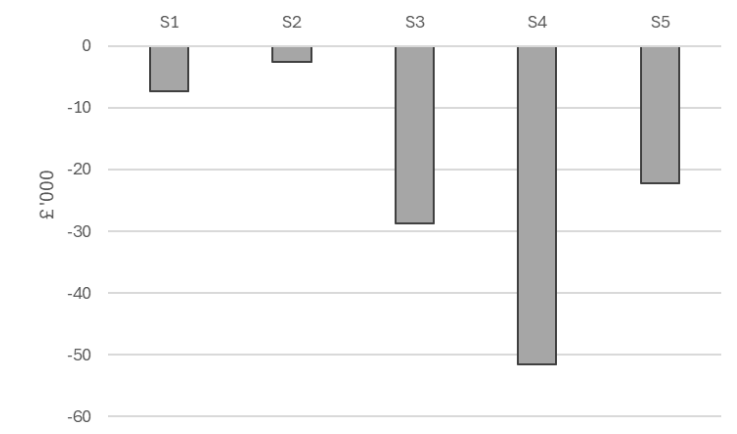

Figure 1: Income foregone under the alternative scenarios (S1 – S5)

From the farm gate, any camelina seed product would first need to be separated from any co-crop, followed by oil extraction. Seed oil quantity and quality will play an important role in the price paid for the oil. Following the oil production the "waste" protein as "cake" also has a value (Boateng et al. 2010; Ceriani et al. 2024). Zubr 2003 evaluated the qualitative variation of camelina grown across 11 locations in Europe up through Denmark and Scandinavia and included some data from Scotland (from one year only). For the study they used summer camelina, but the variation may still be relevant. Oil seed content varied from 39.6% to 44% DM, and crude protein from 39.2 – 47.0 % and crude fibre from 12.5% to 16.8 %. The Scottish camelina had a mean yield of 41.5 % oil, 42.9 % protein and 15.6 % fibre. The value of the protein and fibre as well as the oil will affect the farm-gate price.

**Table 4: Estimated price to cover economic losses under the five alternative scenarios**

| | S1 | S2 | S3 | S4 | S5 (OSR) |
|---|---|---|---|---|---|
| **Est. price (£/t)** | 568 | 540 | 1615 | 1328 | 622 |

## 15. What's known about weeds, control, herbicides etc? taking account of previous trial work in Scotland.

### Weeds

Suboptimal agronomy significantly reduced yields in early Scottish camelina trials conducted in the 1990s and weed control was deemed particularly critical in optimising yields (Pearson and Walker, 1999). Weed profiles for camelina are likely to be similar to those seen in OSR. In the OSR crop, grass weeds and cereal volunteers are relatively easy to control with herbicides selective for monocotyledonous weeds, and dicotyledonous weeds are sometimes harder to manage (for example poppies and mayweeds) particularly where they form rhizomes or have deep tap roots like thistles.

In the Pearson and Walker 1999 trials the herbicide active trifluralin was used prior to crop establishment but is no longer Approved for use in the UK. They also tested metazachlor (either pre or very early post emergence) which was judged as effective for control of dicotyledonous weeds, and cycloxydim to give effective control of monocotyledonous weeds. Both these herbicides are still approved for use in the UK and widely used in OSR crops (Davis et al. 2022). Davis et al. 2022 also confirm that weeds could be a major problem for growing camelina in European trials where they identified that weed competition could result in low camelina yields and also reduced seed oil quality. They report that camelina can be particularly sensitive to herbicides so that control with herbicides can be challenging. Neupane et al. 2022 report similar in US and Canadian camelina crops and trials and highlight that Camelina's sensitivity to herbicides can include sensitivity to residual herbicides used elsewhere in a rotation such that crop damage in camelina can occur up to four years after some residual herbicides are applied. As such, herbicide tolerance trials (particularly those targeting broad leaved weeds) including use in previous crops in the rotation would need to be carefully tested prior to any use in Scottish camelina crops.

In the absence of herbicides then mechanical weed control would be an option and Pearson and Walker (1999) reported light harrowing at the 4-6 leaf stage as being effective from their review of European literature. However, perennial weeds with long tap roots or rhizomes could be problematic and less easy to manage with this approach (Neupane et al. 2022). Leclère et al. 2019 reported that increasing sowing rates could effectively suppress weeds in camelina trials, although Pearson and Walker (1999) link high seed rates to an increased risk of lodging and crop loss in camelina so this would need to be tested in Scottish conditions. Mixed cropping of camelina with peas (Pisum sativum) or barley (Hordeum vulgare) gave effective weed suppression and enhanced camelina yields (Leclère et al. 2019) however Neupane et al. 2022 report significantly (90%) reduced yields where camelina faced competition from barley volunteers so this would need testing before recommending in Scottish conditions. Some of the yield losses associated with weeds relate to competition for resources including nitrogen and increased nitrogen application could be a means to mitigate for a disease burden (Leclère et al. 2019). However, increased nitrogen applications in the autumn period would be inappropriate for many Scottish fields particularly in Nitrate Vulnerable Zones and would risk increasing run off as well the carbon footprint.

Desiccation of the previous crop to camelina with glyphosate would be another means of reducing the weed burden in the camelina crop, as would allowing a sterile period prior to drilling the camelina to allow a flush of weed germination which could be sprayed off with glyphosate. This obviously is dependent on glyphosate remaining Approved for use and could represent an increased reliance on is use. Rotation is key to reducing weed burdens and camelina should not be drilled in fields following OSR, mustard or other Brassica crops (Grady and Nleya 2010; Fleenor 2011). The use of herbicides in camelina could reduce some of the ecosystem services associated with crop. Being small seeded there may be losses at harvest which makes camelina a volunteer problem in following crops, however its susceptibility to herbicides means it might be relatively easy to manage in following crops.

## Diseases

Camelina is considered a disease-resistant crop to many pathogens (Schuster and Friedt 1995) however it is susceptible to a number of pathogens of concern or relevance in Scotland. Pearson and Walker 1999 identified a range of diseases infecting UK trials of which sclerotinia stem rot (Sclerotinia sclerotiorum) was the most significant where it occurred. Other pathogens were judged to be less critical although grey mould (Botrytis cinerea), white blister (Albugo candida) and powdery mildew (Blumeria spp) were also identified in trials. Sclerotinia stem rot led to lodging and large yield reductions (>50%) in an affected trial.

Séguin-Swartz et al. 2010 reviewed diseases of camelina and confirmed its general hardiness to many disease pathogens, however they confirmed its susceptibility to the same range of pathogens as Pearson and Walker 1995. In addition, and of concern and relevance to Scotland, they report camelina's susceptibility to clubroot (Plasmodiophora brassicae). Its susceptibility to clubroot is problematic in Scotland where 30 to 50% of arable land is judged to be affected (Burnett et al. 2019). The period needed for Camelina to yield seed would be more than sufficient to exacerbate the clubroot inoculum loading in contaminated fields as anything greater than 8 weeks is more than sufficient allow the reinfection of roots and the formation of clubroot galls. Clubroot risk can be reduced in OSR crops through the use of resistant varieties and Davis et al. 2022 recorded 22% of OSR in the pesticide survey of crops grown in 2022 in Scotland was of the clubroot resistant variety Crome. This emphasises the high proportion of arable fields where clubroot is likely to be present in Scotland. The control offered from resistant varieties is incomplete however and so extended rotations (>5years) between susceptible crops is the only means to reduce risk. In addition to OSR, other brassica crops including swedes, turnips and brassica containing cover crop mixes are all susceptible so the introduction of camelina as a cover or full crop would impact on other rotation choices and would, for example, need to replace a placement of oilseed in a rotation.

For sclerotinia, while the risk of crop failure in camelina is possibly greatest when grown as a full crop, Pearson and Walker 1999 found infection in the autumn so the risk to camelina as a cover crop cannot be ruled out. As with clubroot other crops in Scottish rotations would also be susceptible to sclerotinia. Fleenor 2011 in their growing guide for Montana recommend that camelina does not follow the susceptible crops sunflower, potatoes, beans and peas. OSR is also affected by sclerotinia which adds significantly to the risk in Scottish rotations.

Séguin-Swartz et al. 2010 identify that downy mildew (Peronospora spp.) can lead to crop losses during the early establishment phases of camelina. They identified camelina accessions in plant collections that were resistant to sclerotinia stem rot, Rhizoctonia and downy mildew such that through further research and trialling resistant cultivars could possibly be developed. However they emphasise that until resistant cultivars or effective management practices have been developed, the susceptibility of camelina to these diseases will limit the cultivation of the crop in areas where these diseases are prevalent.

Camelina research in Northern Kazakhstan in 2018 and 2019 (Utelbayev et al. 2021) identified Alternaria alternate, Alternaria tenuissima and Fusarium acuminatum as pathogens of the crop and tested control options. Biological control (Bacillus subtilis, strain H-13) and an SDHI plus strobilurin mix (boscalid + dimoxystrobin) offered good control. Although Alternaria and Fusarium spp are present in Scotland and could potentially add to the list of foliar pathogens identified above, the risk of them limiting yield in camelina is probably relatively low. As with herbicides, there are no fungicides Approved for use on camelina, including through the use of any Extension of Use Authorisation. Fungicide trials could be established to test crop safety and yield benefits, however, would be of a lower priority than herbicide testing. The rotational soil borne pathogens such as clubroot and sclerotinia are the main concern and can only be effectively managed by extended rotations with non-susceptible crops.

Grower guides from the US and Canada (Ehrensing and Guy 2008; Grady and Nleya 2010) suggest that Camelina is adaptable to many different environmental conditions and the only true limitation is heavy clay soils and organic soils. Ehrensing and Guy, 2008 recommend that camelina does not follow other susceptible crops in a rotation in order to reduce disease risks, and that camelina is easier to place in cereal rather than mixed rotations as a result. Downy mildew can be seed borne, and the sclerotia associate with sclerotinia can also transfer with seed lots so there are implications to seed health and seed testing capacity if camelina becomes an established crop in Scotland.

## Pests

In common with weed and disease risks, the literature review confirms that planting camelina after similar crops, such as OSR, mustard, or other brassicas increases the risk of pest problems common to these crops (Grady and Nleya 2010). Pearson and Walker 1999 found that in Scottish and English trials pest pressures were similar to those seen in OSR with pollen beetles, seed weevils and Silver Y Moth identified in trials although not to levels that limited yield. There are no insecticides Approved for use on camelina, including through the use of any Extension of Use Authorisation.

Neupane et al. 2022 report that camelina is relatively resistant to insect predation and infestation including flea beetles (Phyllotreta spp.) which are a common insect pest of OSR in the UK. They report camelina as appearing to show resistance against the cabbage seedpod weevil (Ceutorhyncus obstrictus) but that stem feeding below the soil by several weevil species was associated with crop failures in autumn planted crops. Although aphids can colonize camelina they are not known to cause significant economic damage (Neupane et al. 2022). Pearson and Walker, 1999 recommend that, based on their experience of Scottish crops, control of weevil (Ceutorhyncus spp.) and pollen beetles (Melegethes spp) would be advisable but since they also note that pest levels were minimal in trials it is unclear why that recommendation is made; it may reflect a different perception on the cost benefits of precautionary insecticide use prevalent at the time.

Although Camelina sativa is considered relatively resilient to pest, weed and disease problems compared to other oil crops such as OSR, there are a number of critical issues which can cause a camelina crop to fail, or which significantly limit yield. There are no plant protection products approved for the crop, with the result that its position in a diversified arable rotation is critical to reducing pest, weed and disease risks. This means it could probably only be grown one year in four at a maximum in Scotland, which obviously limits the maximum amount of available land for the crop annually. The overlap in weed, pest, and disease risks identified for camelina and those identified for OSR and other Brassica crops is high so camelina would have to replace rather than complement them in a rotation. Camelina in a rotation would mean extending the higher yielding OSR crop from one in four /five years to one in eight to ten. Camelina is particularly vulnerable to weed pressures during establishment and highly sensitive to many herbicides. There are no Approved plant protection products for camelina nor any Extension of Use Authorisations either. The literature review shows some pesticide options that could be tested with a potential for use in the crop should that position change. Soil borne pathogens (Sclerotinia and clubroot) are highlighted as particular concerns in Scotland and could only be effectively managed through extended rotations.

Whilst there might be scope to trial and approve plant protection products for use on camelina, it should be noted that their use might reduce some of the ecosystem service benefits associated with the crop.

## 16. Could breeding for oil crops as cover crops provide a longer-term solution, if these crops are not currently optimised for these conditions.

There is significant evidence of environmental x genotypic impact on camelina yield and oil quality components. Jiang et al. 2013 showed a yield difference between two genotypes of 1638 - 1911 kg $ha^{-1}$ to 515 - 591 to kg $ha^{-1}$ depending on the genotype used (averaged across all treatments). Oil content in terms of percentage varied as an interaction with sites from 0.39 % to 0.348%. Jiang et al. 2014 tested 5 genotypes of camelina, across five sites in Canada, and found that genotype affected oil content, protein content, % mono and polyunsaturates, and this was location dependent. They also found that lower temperatures during the reproductive stages increased total seed oil content, without an effect on fatty acid composition. Therefore, understanding the potential impact of the current genotype variation under Scottish climatic conditions and the interactions with agronomic inputs and stress on the transition through different development stages, and phenotyping yield components could help optimise camelina for over wintering, early maturity and yield. Genetic variation in these components does exist within the camelina genepool (Podgoreanu et al. 2015; Rahman et al. 2024)

A whole genome assembly has been developed from both a winter and a spring camelina type (Ontano et al. 2024). The assembles formed 20 chromosomes with a genome size of 667mbases – 714mbase (spring, winter respectively). Shaikh et al. 2024 identified candidate genes in camelina linked to freeze tolerance. A genetic map of camelina has been published and a population of recombinant inbred lines has also been developed (Gehringer et al. 2006). This showed some partial genome homology to other brassica species. This map was used to localise quantitative traits for seed yield, oil content, TGW and plant height. This was undertaken in high (80kg n/ha) or low (0 kg N $ha^{-1}$), with some of the yield loci only appearing in the low N data, suggesting the opportunity of breeding for yield specifically under low nutrient environments.

A recent review by Haslam et al. 2025 also described many routes to developing camelina, focused mainly on methods to adjusting the oil quality components through genetic modification [GM], gene editing [GE], RNAi, alongside GM and GE stacking, to produce multiple novel products. While genetically engineered or edited organism are currently not permitted for field cultivation in Scotland, tools and information gained through such tools make camelina amenable to marker assisted breeding based on the knowledge gained from experimental work and validation of candidate genes.

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