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**The growth, development
and agronomic management of *Camelina sativa***

A dissertation
submitted in partial fulfilment
of the requirements for the Degree of
Bachelor of Agricultural Science with Honours.

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by
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Over the 2013/2014 growing season a Camelina growth trial was undertaken at Ashley Dene, Canterbury, New Zealand to determine the response to different sowing dates, sowing rates and the application of plant growth regulators. This was done to analyse how the crop grows and develops in New Zealand conditions and the effect that agronomic management has.

There were three sowing dates spread out over the spring period and three different sowing rates 2, 4 and 6 kg ha⁻¹ of 'Calena' and a treatment of 1L/ha Cycocel® plant growth regulator was applied to half the subplots. Emergence, plant populations, plant characteristics, growth stages, biomass yields, seed yields, weed yields and oil content was measured.

It was clear from emergence counts that there was significant seedling deaths for sowing date one and two with maximum survival being 31% and 56% respectively, compared to a minimum of 96% for sowing date three and this was attributed to herbicide interaction with cold temperatures. Consequently seed yield was highest for sowing date 3 on 1211 kg ha⁻¹ compared to 883 kg ha⁻¹ and 577 kg ha⁻¹ for sowing date one and two. However despite the significant population decrease sowing date one and three had similar biomass yields.

Sowing rate interactions however were consistent and seed yield, biomass and density all increased with increasing sowing rate. Plant growth regulators only effected plant height and were unnecessary as there was no lodging observed.

This experiment proved that sowing date has more effect on biomass yield than sowing rate and lodging is not a significant issue in Camelina. It also proved how sensitive Camelina is to herbicide damage.

Keywords: Camelina, *Camelina sativa*, linseed dodder, false flax, gold of pleasure, marginal land, biodiesel, biofuel, sowing date, sowing rate, plant growth regulators, oilseed, cardinal temperatures, optimum temperature, maximum temperature, base temperature, thermal time, day length.

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1 INTRODUCTION

Diesel makes up 38% of New Zealand's current fuel demands (Ministry of Economic Development, 2008). Biodiesel is physically similar to diesel and can either be a substitute or additive to diesel that is cleaner burning and more sustainable (US Department of Energy, 2014).

Oil based crops such as oilseed rape, palm oil and soybean oil are the main sources of biodiesel feedstock (Tulloch, 2009). However these require fertile land and most are also used as food crops, this has created a link between food prices and biofuel production (Boddiger, 2007).

The adoption of marginal land biofuel crops such as Camelina (*Camelina sativa*) would not only help better utilise marginal land but it would also decrease the effect of biofuels on food prices and supply (Cai, Zhang, & Wang, 2010).

Camelina is a close relative of oilseed rape (*Brassica napus*) and offers cold hardiness, drought tolerance, and low fertility requirements. Camelina has potential as a fuel component and also as a food component due to high omega-3 oil content (State, 2014).

Despite being a historic plant in the Mediterranean region Camelina only recently gained worldwide attention (Zohary, Hopf, & Weiss, 2012) and there have been several trials in Europe and North America as well some in Chile and Australia (Berti, Wilckens, Fischer, Solis, & Johnson, 2011; Burton et al., 2008; Riffkin, O'Leary, & Acuña, 2012; Urbaniak, Caldwell, Zheljaskov, Lada, & Luan, 2008). There have been very few trials of Camelina viability in New Zealand conditions (Fasi, Martin, Smallfield, & McKenzie, 2012; McKenzie, Smallfield, Fasi, & Martin, 2011).

The objective of this study was to analyse how *Camelina sativa* grows and develops in New Zealand conditions and the effect of agronomic management on its growth and development. Specifically the effects of different sowing dates, sowing rates and the effect of plant growth regulators and thermal time was studied under New Zealand conditions.

This dissertation is presented in six chapters, starting with a literature review, followed by materials and methods, results and then discussion. In chapter 6, a general discussion will describe the practical implications of the findings.

2 REVIEW OF LITERATURE

In this literature review the history, use, physical, environmental and managerial factors that affect the success of *Camelina sativa* in New Zealand will be summarised. Specifically literature on the uses, botanical and physiological features and crop management will be reviewed in detail. The main points will then be summarised in the conclusions section.

2.1 Introduction

Camelina (*Camelina sativa*) is a temperate, perennial, oil seed crop (Ciubota-Rosie, Ruiz, Ramos, & Pérez, 2013). It is also known as Camelina, linseed dodder, false flax or gold of pleasure (Zohary et al., 2012). It was mainly grown as an agricultural crop in Europe up to the 1950's (Johnson, 2011) and until recently Camelina was widely regarded as a 'relic crop' and has gained recent attention as a promising oilseed crop that is cold tolerant and can be grown on marginal land. It experienced huge declines in use in the 20th Century, this is attributed to; the ease of refining oilseed rape (*Brassica napus*), the lack of knowledge regarding polyunsaturated fats and some say harvest difficulty due to the relatively small sized seeds (Davis, 2010)

2.2 Camelina History and Uses

2.2.1 Crop History

Camelina sativa is believed to have originated as a 'secondary crop' meaning it was first discovered as a weed within crops such as flax and then developed into an oilseed crop (Zohary et al., 2012). The first evidence of its existence dates back to circa. 2000 BCE and was found in Auvernier, Switzerland. There was also evidence of its presence throughout central Europe in throughout the Bronze period (1800-1200 BCE). Later in the bronze period there was evidence of *Camelina sativa* in Eastern Europe and then early in the iron period there is also evidence of its presence in the western parts of Asia indicating that the crop was domesticated in central Europe and then spread through Eastern Europe to Asia (Ehrensing & Guy, 2008).

Before World War I *Camelina* was only produced in small amounts in Poland, Russia and Germany but it has now gained renewed interest over its possible use as a low input biofuel.

Biofuels are becoming increasingly important due to their potential ability to replace fossil fuels as a more secure, sustainable and environmentally friendly source of energy (Zohary et al., 2012). However many biofuel crops such as oil seed rape and corn (*Zea mays L.*) take up fertile land effectively taking food out of consumption and further increasing the food deficit. These crops also rely on high inputs, which can be expensive, and some of the inputs are even produced from fossil fuels (Bassam, 2013).

2.2.2 Crop Uses

Human consumption

Gugel and Falk (2006) and Josef Zubr (1997) stated that traditionally Camelina oil was used for direct human consumption. Camelina oil can be used in cosmetic applications as well as a food product for cooking, baking, salads and frying and is high in healthy omega-3 fatty acids (Josef Zubr, 1997). However Vollmann, Moritz, Kargl, Baumgartner, and Wagentristsl (2007) stated that Camelina has high amounts of trans fatty acids in its oil, which increases the risk of cardiovascular disease in humans. There is some concern into the negative effects of glucosinates, which are present in some oils such as Camelina oil, however these concerns are limited and there are no current restrictions on food limits in New Zealand (NZFSA, 2009).

Biofuels

Ciubota-Rosie et al. (2013) found that Camelina had a relatively high oil content and easily extracted and refined oil, as well as being easily transesterified by alkali catalysts which was also confirmed by Wu and Leung (2011). However the biodiesel obtained does not meet all quality standards. The biodiesel contained high levels of linolenic acid methyl ester, polyunsaturated methyl ester and iodine. Zaleckas, Makarevičienė, and Sendžikienė (2012) and (Fröhlich & Rice, 2005) noted that the iodine number in Camelina biodiesel are around 155 when the maximum is 120. This can be combated by mixing it with another biofuel or as stated by Ciubota-Rosie et al. (2013) and Zaleckas et al. (2012) additives can be used to lower the iodine value. The biodiesel was also not believed to have good oxidation stability and Ciubota-Rosie et al. (2013) stated cetane number (CN) ranging from 42.76 to 50.97 and that it did not meet the regulatory cetane numbers (indicates ignition quality) required. According to American Society for Testing and Materials (ASTM) numbers the 100% biodiesel mix does not meet standards at 42.76CN when the minimum required is 47, however the

both the 7% and 15% mix would meet ASTM cetane minimums of 40CN with 50.16 and 49.74 respectively (US Department of Energy, 2013). Zaleckas et al. (2012), (Moser & Vaughn, 2010); Soriano Jr and Narani (2012), Moser and Vaughn (2010) and Ciubota-Rosie et al. (2013) all conclude that the high levels of unsaturated fatty acids are the most significant barrier to Camelina being an effective biofuel crop. Ciubota-Rosie et al. (2013) also noted that genetic engineering of Camelina and long term conventional breeding would be a good tool to reduce unsaturation and molecular weight which would make it significantly more suitable as a biofuel crop. Muppaneni et al. (2012) and Soriano Jr and Narani (2012) found Camelina biodiesel to have viscosity similar to that of regular diesel. It also found the 'pour point' (point which biodiesel starts to turn solid) was -13 to -15°C and although this just meets the required standards it is significantly higher than regular diesel at -20°C. However it is similar to other biofuels such as soy and canola. Soriano Jr and Narani (2012) noted the EPA mandated the use of ULSD (Ultra Low Sulphur Diesel) in the USA, Camelina has approximately 5.46ppm of S which is just below the required 6ppm of S. Fröhlich and Rice (2005) also showed that Camelina has good lubricating properties. (Paulsen, Wichmann, Schuemann, & Richter, 2011) also showed that additives could be used to double the oxidation resistance of Camelina biofuels.

Animal feed

Josef Zubr (1997) stated that the seed meal could be potentially is of high value as feed for poultry, swine and ruminants. R. Russo and Reggiani (2012) noted glucosinates provide a significant barrier to the use of Camelina meal or seeds as an animal feed. Glucosinates have been shown to affect animal growth, reproductive performance, as well as intake and palatability of feed. Although Camelina has relatively low levels of glucosinates in the seed meal after oil pressing which ranges from 15.2 to 24.6 $\mu\text{mol kgDM}^{-1}$. However these levels are significantly higher than those required for feed use in both Europe which are 1 – 1.5 $\mu\text{mol kg}^{-1}$ of feed for monogastric animals (Andersson et al., 2008) and restrictions are also present in the USA. R. Russo and Reggiani (2012) also stated that the use of breeding was effective at reducing oilseed rape from 50-150 $\mu\text{mol kgDM}^{-1}$ to under 2 $\mu\text{mol kgDM}^{-1}$ so could also be effective for Camelina. However there is concern that lower concentrations of glucosinates may result in higher concentrations of sinapine which decreases palatability to animals, however more research needs to be done into the interaction of these two compounds. Peiretti and Meineri (2007) noted the diminishing nutritional value of the herbage as the crop advances morphological development that is mainly associated with the

lignification of the plant. Which would significantly diminish its use as a forage crop particularly in late spring to summer. (Schuster & Friedt, 1998) noted the use of Camelina meal was similar to oilseed rape meal and has high protein and energy. It also been noted that it is only part of a balanced amino acid diet and should not be used exclusively. However the study made no comment on the presence of glucosinates, which limit its use as an animal feed.

2.3 Botanical and physiological features

2.3.1 Botanical description

Camelina sativa is a member of the Brassicaceae family, which is also known as the crucifers or mustard family. It is closely related to oilseed rape and is only one of four known member of the *Camelina* genus, and is the most documented and well known (Ehrensing & Guy, 2008). There are five species of *Camelina* with *sativa* being the oilseed crop and species *macrocarpa*, *pilosa*, *alyssum* and *lincola* being the wild and weedy forms of the plant found across Europe, North America and Asia. *Camelina* species; *macrocarpa* is identifiable by its small fruit, *pilosa* is identifiable by its early flowering time and hairy appearance, while *asyssum* and *lincola* both have long erect stems and hard fruit. The key difference between these weed subspecies and the crop subspecies (*sativa*) is the larger pear-shaped fruit, bigger seeds, typically 1.5-2.0 mm long, and a higher amount of edible oils, typically 27-31% (Zohary et al., 2012).

2.3.2 Camelina Seed

Seed Size

Gugel and Falk (2006) noted that *Camelina* typically has small seeds, especially in comparison with other brassica crops, and they recorded them at 1.5 to 1.8 g per 1000 seeds. Although there was a wide range across many papers and cultivars; Blackshaw et al. (2011) found 1.2g and 1.18g per 1000 seeds, Johnson (2011) recorded it ranging from 0.92g to 1.46g per 1000 seeds and Gehringer, Friedt, Lühs, and Snowden (2010) found a wider range of 0.7g to 1.6g per thousand seeds similar to another large study by (Berti et al., 2011), which showed a range from 0.8g to 1.8g per thousand seeds. The large variation was likely caused by the different trials being run in different environments using a range of cultivars.

Gugel and Falk (2006) stated that cultivars with bigger seed size are available but this has shown to have lower oil contents and seed yields and Vollmann et al. (2007) confirmed this

with a negative correlation between 1000- seed weight and oil content ($r^2 = -0.92$). However samples of bigger seeds show high levels of variation meaning there is a breeding opportunity to select bigger seeds that also have higher oil content and yields (Vollmann et al., 2007). Johnson (2011) recorded 10 and 9 seeds per pod across two different cultivars but (Vollmann et al., 2007) noted that bigger seeds have less seeds in each pod and found better oil yield performance from smaller seeds which they attributed to be due to them containing more seeds in each pod as well as higher oil percentage. This is in keeping with many other oilseed crops, which have also shown a slight negative correlation between oil content and 1000-seed weight (Gugel & Falk, 2006). Gugel and Falk (2006) noted a lack of seed dormancy in *Camelina* meaning there would be lower instances of post-harvest weed infestations of *Camelina* in following crops.

Germination Rate

There is little published data regarding the germination rates of *Camelina* but Johnson (2011) recorded germination as over 95% for the tested Canadian cultivars, which was also confirmed with similar rates found by Blackshaw et al. (2011) of 95% and 99% for two different cultivars.

Oil Content

Fasi et al. (2012) found the average oil content of *Camelina* to be 35%, slightly below the 42% it found for oilseed rape and similar to that found by Ciubota-Rosie et al. (2013) of 35-45% and slightly higher than found in A. D. Pavlista, Baltensperger, Isbell, and Hergert (2012) of 31.8%. While Gugel and Falk (2006) found a range from 38 - 43%, similar to the 39.6 to 44.1% range found by J Zubr (2003). Angelini, Moscheni, Colonna, Belloni, and Bonari (1997) had the widest reaching measure of 24-43%. The wide range of *Camelina* oil content indicates the possibility of increased breeding to create higher oil cultivars (Rodríguez-Rodríguez, Sánchez-García, Salas, Garcés, & Martínez-Force, 2013). Vollmann et al. (2007) indicated this has already happened in some cases with a significant difference in the oil content across cultivars, which ranges from 15.5% (CAS-CS7) to 41.7% (CAS-CS32).

Oil composition

Vollmann et al. (2007) noted that *Camelina* oil is made up of 90% unsaturated fatty acids with 33% being mono-unsaturated and 54% being unsaturated (2 or 3 double bonds). Ciubota-Rosie et al. (2013) noted most common fatty acids are linolenic acid (C 18:3) making up 30-40%, linoleic acid (C 18:2) making up to 15-20%, oleic (C 18:1) making up to 10-25%

and eicosenic/gondoic acid (C 20:1) making up approx. 15% (Abramovič, Butinar, & Nikolič, 2007). Vollmann et al. (2007) found linolenic acid content had an average range of 29-35% with cultivar crosses between small and large seeds exhibiting higher linolenic content, there was also evidence that linolenic content was negatively correlated with time to flowering and oil content, but positively correlated between with 1000 seed weight. Euristic acid (C 22:1) was generally between 3 and 4.5%, but some of the mutant lines Vollmann et al. (2007) tested showed a greater variability with one showing higher euristic acid content (CMUT-838/1) of 4-6.5% and the others showing a range of 2-3%. There was significantly higher levels of linolenic acid during a cold season which may be explained by Velasco, Fernández-Martínez, García-Ruiz, and Domínguez (2002) which showed in general oilseed crops produce more polyunsaturated fats when they have low temperatures during the seed fill periods while higher temperatures result in higher saturated fatty acid concentration, there were also lower levels of euristic acid in the same year found by Vollmann et al. (2007). Rodríguez-Rodríguez et al. (2013) also found temperature and fatty acid concentrations to be positively correlated with linoleic and arachidic acids and negatively correlated with eicosadienoic and eicosatrienoic acids. It was also stated that high levels of linolenic and linoleic makes the oils prone to oxidation, which is an undesirable trait for most industrial uses, especially biofuels.

Protein content

Gugel and Falk (2006) found that average crude protein (CP) per kgDM of Camelina seed ranged from 27 to 32% in keeping with the Brassica checks it used for comparison that ranged from 27 to 32%. However these Camelina figures are slightly higher than those recorded by Peiretti and Meineri (2007) of 24.5% CP but point to a wider range of protein content also reinforced by Marquard and Kuhlmann (1986) with a range of 23.5 to 30.1% CP. There was also a range of figures for protein on a fat free DM basis such as J Zubr (2003) with 41.8 to 44.8%, (J Zubr, 1988) with 45% and Korsrud, Keith, and Bell (1978) with 45.1% to 46.9% which show less variability and therefore may be more comparable.

Peiretti and Meineri (2007) also measured the protein present in the plant with the highest protein content being recorded at the vegetative stage of 220 g kgDM⁻¹ and decreasing down to the ripe seedpod stage at 92g kgDM⁻¹.

Fibre content

J Zubr (2003) found a relatively small variability of crude fibre content (on a fat free basis) in camellia seed ranging from 12.5% to 16.8% across 7 different European countries with an average of 14.5% crude fibre. Korsrud et al. (1978) recorded 11.4% and 9.8% crude fibre on a DM basis.

Development

Fasi et al. (2012) found that autumn sown Camelina took 72 days to reach stem elongation, compared to 148 for oilseed rape, 93 days to reach 50% flowering compared to 45 days for oilseed rape and 86 days to harvest compared with 72 for oil seed rape, taking a total of 259 days from emergence to harvest. However in the spring sowings oilseed rape took 127 and 112 days to go from emergence to harvest but Camelina took only 98 and 91 days and ended up with higher yields than autumn sowing. Gugel and Falk (2006) found that it took an average of 40, 41 and 42 days for Camelina to reach flowering across several different locations and also found that it took an average of 86, 94 and 96 days for Camelina to reach maturity, consistent with Fasi et al. (2012).

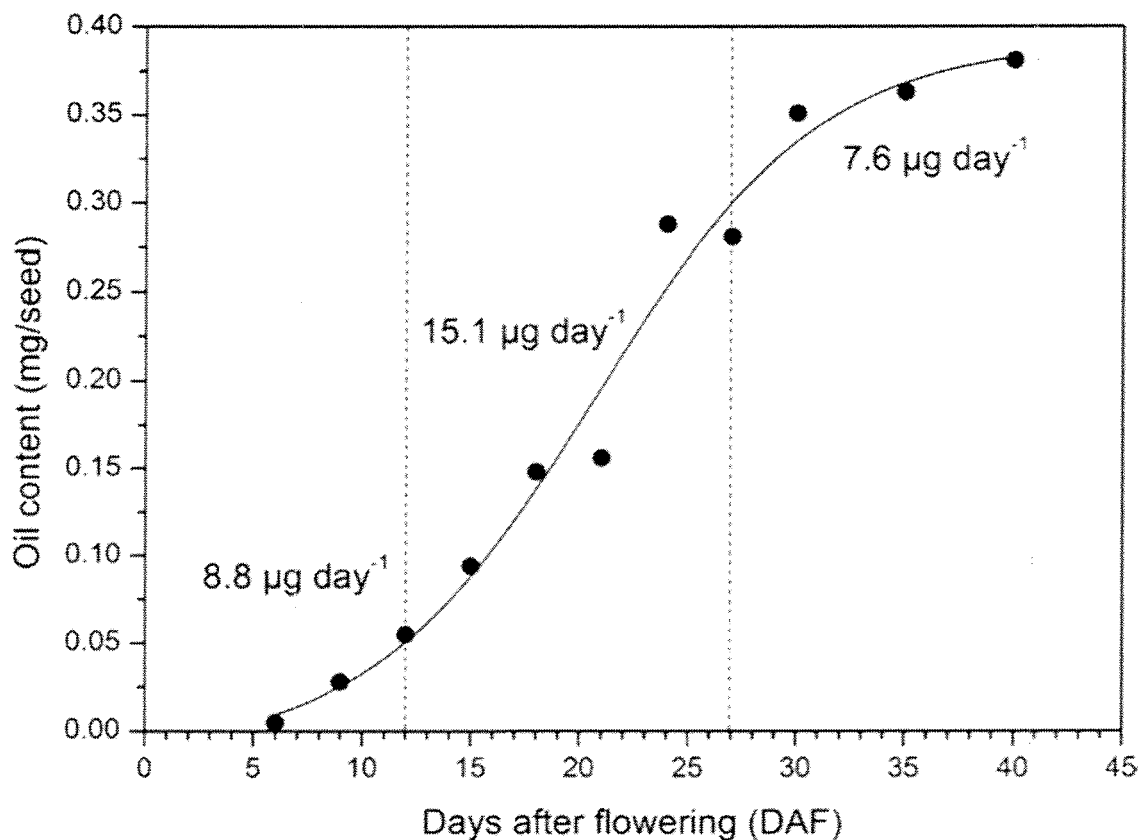


Figure 2.1 Rate of oil accumulation in *Camelina sativa* seed at different stages of development. (Rodríguez-Rodríguez et al., 2013)

Rodríguez-Rodríguez et al. (2013) found a continuous accumulation of oil during seed development, although the rate at which it accumulated varied (Figure 2.1). Accumulation started slower at 8.8 µg/day then increased to 15.1 µg day⁻¹ before tapering off to 7.6 µg day⁻¹. The levels of saturated fatty acids (palmitic and stearic) also peaked 6 days after flowering (at 23.4 and 24.4%) and then continued to decrease until the plant was mature. This was the opposite of linolenic acid, which increased from 4.3% at 6 days after flowering to 41% at maturity.

Water use and moisture stress

Gugel and Falk (2006) performed a trial in western Canada over 3 years one of which was dryer than usual and the other was considered a drought. They found that Camelina survived well in dry conditions and saw better germination and stand establishment in comparison to some Brassica species trialled. Camelina also matured 3-4 and 6 days earlier in drought conditions in comparison to higher rainfall years. Berti et al. (2011) also stated that the lower rainfall was likely the cause of faster maturity in one of their Camelina fields. Fleenor (2011) noted that Camelina responds well under drought stress and may be better suited to low rainfall areas than most other oilseed crops. Angelini et al. (1997) noted that a late season drought caused a faster seed filling and therefore seed weight was severely down with seed yield being below 1 g plant⁻¹ and lower oil content was recorded of 24 to 33%. Hunter and Roth (2010) also found that Camelina did not yield in high rainfall environments.

J Zubr and Matthäus (2002) concluded that Camelina was flexible across a variety of different climatic and soil conditions but oil composition varied greatly across these different conditions. McKenzie et al. (2011) trialled a range of oilseed crops on marginal New Zealand soils and although oil seed rape slightly outperformed Camelina in nearly all categories for autumn-winter planting on a stoney and a pumice soil and both autumn-winter and spring plantings on a wet and infertile soil including oil yield (kg ha⁻¹), seed yield per ha and total DM yield per ha. Spring sown Camelina did outperform oilseed rape in several important

categories on a stoney and a pumice soil such as oil yield/ha and seed yield/ha however not in total DM ha⁻¹. When specifically looking at oil yield (kg ha⁻¹) oilseed rape performed better at autumn-winter plantings across all 3 tested marginal soils. However on the stoney soil Camelina outperformed oilseed rape in spring planting with 50kgN ha⁻¹ Camelina yielded 145kg ha⁻¹ compared to oilseed rape yielding 130kg ha⁻¹ and at 150kgN ha⁻¹ Camelina and oilseed rape yielded 271kg ha⁻¹ and 117kg ha⁻¹. Spring sown Camelina on pumice soil also outperformed oilseed rape yielding 520kg ha⁻¹ at 50kgN ha⁻¹ and 966kg ha⁻¹ at 150kgN ha⁻¹ compared to oilseed rapes 463kg ha⁻¹ and 681kg ha⁻¹. However on the wet and low fertility soil Camelina was significantly outperformed by oilseed rape. Its poor performance was also noted by Hunter and Roth (2010) that showed Camelina may not perform well in poorly drained soils and Josef Zubr (1997) stated the Camelina does not grow very well in heavy clay or organic soils.

Temperature

Camelina has been recognised as a temperate crop (Ciubota-Rosie et al., 2013), however there has been very little research on the effect of temperature on yields although it is acknowledged as a likely impact of oil composition and is likely positively correlated to the speed of development (Vollmann et al., 2007). AFLP fingerprinting data shows a range of clustering of cultivars to certain temperatures indicating significant variation between cultivars with regard to optimum temperature (Francki et al., 2010). Schillinger, Wysocki, Chastain, Guy, and Karow (2012) researched Camelina in Canada and the plants experienced -23°C air temperatures and 32km/h winds for 8h and came out with a 70% survival rate which is comparable to winter wheat in the same region. Indicating a strong resistance to damage from cold temperatures and wind.

R. RUSSO (2013) stated that some winter cultivars of Camelina require vernalisation while the spring cultivars do not, however there are very few details published regarding the different cultivars of Camelina that are currently used. R. Gesch and Cermak (2011) also noted that Camelina is photoperiod sensitive however it did not show any evidence or source to back this up.

V. Russo, Bruton, and Sams (2010) found Camelina had optimum germination at temperatures 16°C and 21°C with 100% germination occurring within 2 days, 32°C also

occurred within 2 days but there was less than 80% total germination, 4°C and 10°C also received 100% germination but it took longer to achieve,

Gugel and Falk (2006) suffered no frost damage on Camelina despite oilseed rape being damaged by late frost during the same experiment and consequently had lower yields. Indicating it is very resistant to cold temperatures.

Harvest Index

Berti et al. (2011) stated harvest index in oilseed crops commonly sits between 30-35% with canola usually sitting around 30%. They recorded a significant range of harvest indexes from a late-autumn sowing of 10.2% to an early spring of 39.5%, however no significant effect of sowing date was found indicating there is a large variability in harvest index for Camelina. This was a slightly wider range to that found by R. Gesch and Cermak (2011), 13% to 29%. In both there was however a concentration around 20-30%.

Breeding

Vollmann et al. (2007) noted that when breeding was selected for increased seed size, there were adverse results including grain yield, oil content and fatty acid profile. Ciubota-Rosie et al. (2013) stated breeding was required to reduce unsaturation and molecular weight of oil, Francki et al. (2010) noted this could be done using a cultivar originating out of the Ukraine with ideal aspects as a parent crop for breeding for these desired characteristics. Schuster and Friedt (1998) noted the need for breeding to reduce glucosinolate content, however this is only of secondary importance, as it only needed for animal feed purposes.

Séguin-Swartz, Nettleton, Sauder, Warwick, and Gugel (2013) trialled the interspecific hybridization of Camelina with several other species from the Camelina family. These included *C. microcarpa*, *C. alyssum* and *C. rumelica* subspecies *rumelica* and *transcaspica*. While several of the crosses did not warrant further exploration, Camelina x *C. alyssum* was highly fertile and was largely self-seeded and may be worth further exploration.

Büchschütz-Nothdurft, Schuster, and Friedt (1998) trialled mutagenesis on Camelina to attempt to modify the fatty acid composition, this resulted in significant variations in the linolenic acid concentrations with 3rd generation mutagenesis plants having a range of 20-36% linolenic from a 30% linolenic parent. The fourth generation was then created from a high linolenic acid seed creating linolenic acid content of up to 40%.

Zakharchenko, Kalyaeva, and Buryanov (2013) trialled transgenesis with a synthetic antimicrobial peptide, this resulted in a successful transgenic crop, which showed evidence of greater stability and resistance to plant pathogens such as soft rot (*Erwinia carotovora*) and *Fusarium* spp.

2.4 Crop Management

2.4.1 Planting method

Schillinger et al. (2012) found both broadcasting and direct drilling successful planting methods for Camelina and both showed no significant difference in stand establishment. However there were some differences; the formation of fragile soil crusts after rain may have hindered emergence for direct drilled seeds and a lack of rain after broadcasting may have both negatively effecting plant stand. Josef Zubr (1997) stated that repeated harrowing is an effective way to eliminate germinating weeds before sowing. They also state that broadcasting is a more effective way to reduce weed competition than direct drilling. R. Gesch and Cermak (2011) compared direct drilled and chisel ploughed Camelina. Direct drilled plants flowered 1-2 days earlier than conventionally planted plants possibly due to less freezing stress to direct drilled plants. Tillage was shown to have no effect on seed yield and biomass yield in 2007-2008 season. While the 2008-2009 season showed higher seed yields for no till. Lodging was found to be effected by till in the 2007-2008 season but not the 2008-2009 season. Till also effected the Harvest Index with the chisel ploughed Camelina showing higher harvest index than no-till. In the 2007-2008 period there was no significant effect of tillage on oil content but in the 2008-2009 season the no-till system yielded 70g kg⁻¹ higher. The no-till performed better and this was likely due to warmer soil temperatures due to the insulation of previous organic matter from the cold and also less water absorption into the soil.

2.4.2 Planting Date

Wysocki and Sirovatka (2008) stated that a wide range of sowing dates are applicable for Camelina and it depends on the climate when is most appropriate. Fasi et al. (2012) found that the sowing date effected the oil content with autumn sown (March and April) Camelina having 37.6% oil content and the spring sown (September and October) having 32.9 and

32.8% oil content. The timing of planting was also shown to effect the growth stages of the plant with the March, April, September and October showing decreasing time between 50% emergence and stem elongation of 72, 72, 32 and 22 days respectively. They also showed decreasing time between stem elongation and flowering with March, April, September and October respectively showing flowering 103, 82, 18, 16 days after stem elongation. Flowering to harvest once again showed longer between stages for the autumn sown Camelina with 84 and 87. The spring sown Camelina was 48 days for September sown and 53 for October sown. A. Pavlista, Isbell, Baltensperger, and Hergert (2011) ran a Camelina trial in Nebraska run over 2005 and 2006, however it's trials were planted from spring to early summer and they were significantly less than Fasi et al. (2012) with days from flowering to seed maturity ranging from 40 days in early spring to 23 days in early summer. Fasi et al. (2012) also found that from emergence to harvest in March, April, September and October respectively showed decreasing times from 259, 241, 98 and 91 days. This is similar to A. Pavlista et al. (2011), which recorded planting to seed maturity, which ranged from 127 days in early spring to only 64 days in early summer. This is in keeping with similar early spring numbers from Berti et al. (2011) ranging from 105 to 159 days. Berti et al. (2011) also found days from sowing to harvest to be 200 to 234 days across different locations for late autumn planting, 185 to 231 for early winter, 152 to 202 days for mid-winter and 123 to 155 for late winter. Which is a downward trend but there is no statistical significance is proven in this.

Fasi et al. (2012) found there was also a significant difference between plant population across sowing dates, the population at establishment are stated and the population at final harvest are shown in brackets. For March April, September and October respectively these were 246 (30), 241 (74), 323 (281), and 290 (223) plants m^{-2} . This however does not line up with seed yields, which were 664, 1162, 1412, and 869 $kg\ ha^{-1}$ respectively. Fleenor (2011) noted that decreased yields have been found for late spring planted Camelina. Schillinger et al. (2012) ran experiments with planting date in the Pacific Northwest of the USA. They found that there was a positive effect of earlier planting date on plant population (plants m^{-2}) however this was a very weak trend for a Washington state trial but a much tighter trend was observed in Oregon. They also looked at the impact of planting date on seed yield ($kg\ ha^{-1}$) however there were very mixed results with one Washington trial showing no effect of sowing date, one Oregon trial showing an increasing trend and another showing a bell curve while an Idaho trial showed a decreasing trend. These results were very mixed and were

likely heavily impacted by soil type and different weather conditions. A. Pavlista et al. (2011) showed that planting date did not affect oil content. But it did effect oil composition, earlier sowing dates had higher concentrations of C 18:3 (linolenic acid) ranging from 37.1% down to 32% at later sowing dates. This is in direct contrast to C 18:1 (oleic acid) which increased from 14.9% at earlier sowing dates to 16.2% at later sowing dates and lower concentrations of C 18:2 (linoleic acid) at earlier dates from 18.9 and increasing up to 21.1% at later sowing dates. A. Pavlista et al. (2011) also showed that *Camelina* matured within 7 days of each other regardless of sowing date. However A. Pavlista et al. (2011) did not test any autumn sown *Camelina* but instead a range of dates ranging from spring to early summer, so results only reflect these time frames.

Berti et al. (2011) studied the effect of sowing date across a range of locations in Chile with sowing dates ranging from late autumn to early spring. The harvest index showed nearly no significant differences apart from one location which showed a significantly lower harvest index for the first sowing date in late autumn and a significantly higher sowing date for the last sowing date in early spring. This is in keeping with the range of harvest index figures found by R. Gesch and Cermak (2011) across a range of dates in autumn, which found that harvest index increased with later sowing dates before decreasing slightly in late autumn. Berti et al. (2011) found that all five locations showed significant differences of biomass yield with four of those five showing the earliest late-autumn sowing date as the highest biomass yielding and then decreasing gradually with a large decrease between the mid and late winter sowing dates. There was a large range of different biomass yields across locations ranging from 4,850 kgDM ha⁻¹ to 12,380kgDM ha⁻¹ at the earliest sowing date and 2158kgDM ha⁻¹ to 5357kgDM ha⁻¹ for the latest early-spring sowing date, with most locations decreasing by about 50% from the first to last sowing date. The seed yield showed significance on 5 out of 7 of the trials, showing seed yield decreasing with later sowing dates with some increasing at the early winter sowing date before decreasing. Berti et al. (2011) also showed that there was an effect of sowing date on seed oil content in 3 out of 5 locations however two show seed oil content increasing with some later sowing dates while another shows decreasing oil content with later sowing dates. R. Gesch and Cermak (2011) also indicated seed oil content was likely to increase with planting date.

2.4.3 Planting Rate

Johnson (2011) found that increased sowing rate had a positive effect on plant population (plants m^{-2}) but at a decreasingly marginal rate. This means decreasing percentage emergence of plants ranging from 59% at 12 seeds m^{-2} to 28% at 1600 seeds m^{-2} . Johnson (2011) also found increasing seed yield with increasing planting rate up to 316 - 437 seeds m^{-2} with a peak yield of 1716 to 1772 kg ha^{-1} before decreasing and flattening off at about 1700 kg ha^{-1} regardless of increasing sowing rate. Planting rates of greater than 200 seeds m^{-2} was also shown to decrease flowering time by 1 day and reduce maturity from 96 days to 89 to 90 days.

Wysocki and Sirovatka (2008) recommended sowing rates of 3.4-5.6 kg ha^{-1} and noted lower sowing rates often resulted in poor plant stand. This is significantly lower than the 5-7 kg ha^{-1} guide recommended by Josef Zubr (1997)

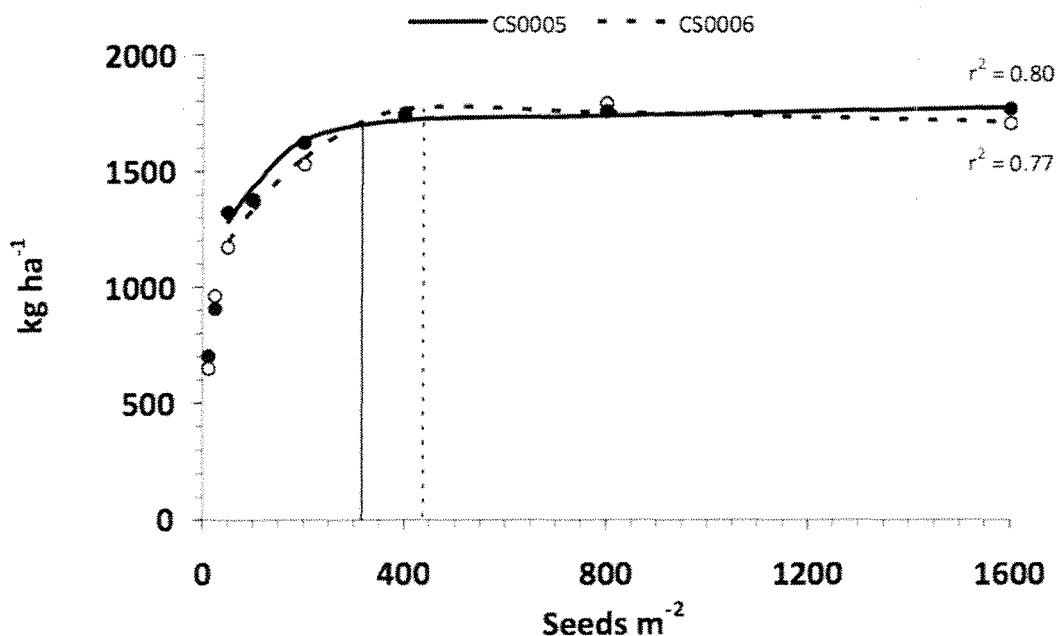


Figure 2.2 Relationship between planting density (seeds m^{-2}) and camelina seed yield (kg ha^{-1}). (Johnson, 2011).

Pests

Fasi et al. (2012) observed seed loss due to bird damage from Camelina however this was noted to be less than brown mustard and oilseed rape, which were both part of the same

trial. McKenzie et al. (2011) also noted bird damage to Camelina but was also observed to be less than that of brown mustard and oilseed rape. However no actual data was recorded regarding the extent of the losses. Similarly A. Pavlista et al. (2011) noted no bird damage to Camelina but bird damage to both brown mustard and oilseed rape. Gugel and Falk (2006) advocated the choice of Camelina as a crop resistant to insect pests however they found flea beetles but did not feed on the plants in contrast to nearby brassicas. This preference was also confirmed by A. Pavlista et al. (2011). Wysocki and Sirovatka (2008) noted that aphids and cabbage seed pod weevil which both commonly affect canola have not been observed to have any affect on Camelina. Berti et al. (2011) also observed cutworms (*Agrotis* spp.) severely damaging both mustard and canola but did not observe any damage to Camelina.

2.4.4 Diseases

Fasi et al. (2012) observed the presence of *Rhizoctonia solani*, which was believed to contribute to the significant drop in plant population along with the early bolting of plants. Wysocki and Sirovatka (2008) also noted that Camelina might be susceptible. Gugel and Falk (2006) observed Blackleg disease (*Leptosphaeria maculans*) on brassicas that were part of the same trial but none was observed on Camelina. Aster yellows disease was observed at <1% on both Camelina and the brassicas in 2001 and 2002 but was observed mainly on Camelina of up to 3% incidences. Berti et al. (2011) also found a susceptibility of Camelina to aster yellows disease. Gugel and Falk (2006) found there was not significant evidence of preference that the leafhopper vector (*Macrostelus quadrilineatus*) feeds preferentially on Camelina and more research needs to be done. Fleenor (2011) noted that Downy mildew has been observed in Camelina in the Pacific Northwest of the USA. It also noted the Camelina has a susceptibility to sclerotinia stem rot but there has been no reports of major outbreaks.

2.4.5 Weeds

Wysocki and Sirovatka (2008) stated that Camelina is competitive with weeds but only once the crop canopy has been formed. Gugel and Falk (2006) noted that weed populations have a big impact on the uniformity of the crop, which tends to be more of a problem with earlier planted Camelina and it mentions stinkweed (*Thlaspi arvense*) as a particular problem in Western Canada. Schillinger et al. (2012) found winter annual broadleaf crops tumble mustard (*Sisymbrium altissimum*) and tansy mustard (*Descurainia pinnata*) and noted they

are fall germinating and therefore for later sowing dates can be controlled prior to planting. Russian thistle (*Salsola iberica*) was a significant weed in a Washington experiment and was significantly higher at 24 plants m⁻² in late-winter plantings and 6 plants m⁻² in spring plantings.

2.4.6 Lodging

Solis, Vidal, Paulino, Johnson, and Berti (2013) only found lodging to be a problem at one out of four of the locations they did trials at and only with >75kgN ha⁻¹ added N. However this location already had significantly higher nitrogen levels than the other locations. Johnson (2011) visually rated their trial based on the degree of lodging and found that lodging decreased with increasing sowing rates from 12 seeds m⁻² to 800 seeds m⁻² and then rising at 1600 seeds m⁻². R. Gesch and Cermak (2011) found there was a significant effect of planting method on the occurrences of lodging and chisel ploughed Camelina was more likely to exhibit lodging than no till planted Camelina.

2.4.7 Fertiliser

Johnson (2011) found that Camelina responded positively to increasing nitrogen rates up to 95-116kgN ha⁻¹ before plateauing. Which included the optimum of 100kgN ha⁻¹ suggested by Josef Zubr (1997). This is very similar to the optimum found by Wysocki and Sirovatka (2008) of 89-100kgN ha⁻¹. Solis et al. (2013) found the highest seed yields at 150kgN ha⁻¹ and 300kgN ha⁻¹ depending on location. It is also worth noting that they did not have many Nitrogen replicates around the optimum and only ran a trial with 0, 75, 150 and 300 kgN ha⁻¹. However they also found decreasing oil content with increasing nitrogen levels from 43.7% at 0kgN ha⁻¹ added to down to 41.7% at 300kgN ha⁻¹. This indicated that the increase in seed yield may be countered by decreasing oil content. Solis et al. (2013) also found no effect of nitrogen levels on TSW. Biomass also showed a significant increase to 75kgN ha⁻¹ but plateaued off after that. The highest harvest index was received without any N applications indicating that N applications may increase the biomass yield more than the seed yield. In Solis et al. (2013) applications over 75kgN ha⁻¹ also increased lodging. McKenzie et al. (2011) noted that the higher N input of 150kgN ha⁻¹ over 50kgN ha⁻¹ resulted in higher seed yield and oil yield for two of the locations trialled but had very little effect on another location at which Camelina did not perform well due to the wet conditions. Solis et al. (2013) also found that added S and P actually caused a decrease in seed yield from 1750kg ha⁻¹ with no P or S

to 1650kg ha⁻¹ with 100kgP ha⁻¹ and 1550 with 100kgP ha⁻¹ and 40kgS ha⁻¹ added, however this is likely to be because of current soil fertility levels.

2.4.8 Chemical Applications

Camelina is not tolerant of many herbicides, which can make weed control difficult. Johnson (2011) trialled many different herbicides and found them not suitable, these included; imazamethabenz, fluroxypyr-MCPA, 2,4-D Amine, MCPA Amine, bentazon, bromoxynil, 2,4-D B, florasulam-MCPA, clopyralid, glufosinate, sulfentrazone, isoxaflutole, imazamox: imazthapyr 1:1, thifensulfuron : tribenuron, clomazone and dimethanamid. So far Camelina has been found to be tolerant of three herbicides cledthodim, quizalifop-p-ethyl and sethoxydim. One of these (quizalifop-p-ethyl) is also registered for grassy weed control of Camelina in Canada. Pendimethalin was also found to have 'acceptable levels of injury' but may have trouble getting registered. However as there are few or no registered herbicides for the use on Camelina, Wysocki and Sirovatka (2008) recommends using non-selective herbicides such as glyphosate to kill all weeds before planting.

2.4.9 Dual and Intercropping

R. Gesch and Archer (2013) studied the potential for double cropping in the upper Midwest of the USA and looked at Camelina followed by soybeans, oilseed sunflower or forage millet. The results showed the most effective crop was soybean however the profitability was lower than a mono-crop of soybeans in the first year (approx. 77 to 84%) and slightly higher in the second (99 to 111%). However this would be highly variable depending on changing crop prices.

Akk and Ilumäe (2005) trialled growing peas and Camelina together, there was no economic analysis but there did appear to be advantages from the peas fixing nitrogen and the weed suppression from the Camelina canopy. However the competition appeared to negate the positive impacts, but the experiment did not compare to monocropping and simply ran a dual-cropping trial.

2.4.10 Harvest

Fleenor (2011) stated that in Montana harvest usually takes place in mid-summer but varies depending on sowing date, precipitation, temperature and harvest method. But Wysocki and Sirovatka (2008) noted in Oregon, Washington and Idaho that harvest occurs nearer the end

of the summer. Fleenor (2011) also recommends harvesting when moisture was 10% or lower, slightly higher than the 8% recommended by Wysocki and Sirovatka (2008) and lower than 11% recommended by Josef Zubr (1997). Both Fleenor (2011) and Wysocki and Sirovatka (2008) suggest oilseed rape moisture metre settings can be used for accurate readings. Fleenor (2011) stated Camelina is usually direct-combined but it can be swathed and windrowed after. Wysocki and Sirovatka (2008) stated this may be a good option when there are weed species present such as Russian thistle (*Kali tragus*). Fleenor (2011) stated when swathing it is recommended to be done when two thirds of the pods turn from green to yellow, and to leave as much stem as possible. Camelina can be harvested on the same settings as oilseed rape or Lucerne seed but the fan speed will need to be reduced due to the low seed weight. Due to the small seed sizes losses of Camelina may be higher than oilseed rape but no research has been conducted on this.

While seed shatter is mentioned in several papers few actually record the specific effect apart from Johnson (2011) which noted seed shatter losses at an average of 6% but was highly variable between cultivars with one recording 3.6% shatter loss and another recording 8.2% shatter loss. This seems to be similar to oilseed rape for the area which had an average of 5.4% loss from shatter (Gan, Malhi, Brandt, & McDonald, 2008). It therefore appears that seed shatter is similar between oilseed rape and Camelina.

2.5 Conclusions

- Camelina is suited to marginal, low fertility land.
- Camelina does not yield well in wet conditions or in heavy soils and yields best in free draining soils and dry conditions and is drought tolerant.
- Camelina is very sensitive to herbicide applications.
- Early spring sowing has proven to have highest seed yields in most conditions
- Autumn sowing has proven to have highest biomass production.
- Camelina has very small seeds, thousand seed weight of 0.8g to 1.8g, this means it needs to be sown shallow and needs a fine seed bed.
- Pests and insects are not a significant problem for Camelina and they often do not feed on them.
- There is significant potential for Camelina breeding for increase oil, thousand seed weight and oil composition.

3 MATERIALS AND METHODS

3.1 Laboratory Experiment

A laboratory experiment was set up in the field service centre at Lincoln University, Lincoln, Canterbury, New Zealand. The experiment was run using three different *Camelina sativa* cultivars; Accession number 4164, Calena and Suneson. Petrie dishes were lined with filter paper, moistened with water and 50 seeds of the relevant cultivar were placed as evenly as possible on the top of the filter paper. These were then placed in a incubator to control temperature at eight different temperatures (5°C, 10°C, 15°C, 20°C, 25°C, 30°C, 35°C, 40°C) with 3 replicates. Germination counts were then taken every 12 hours until the germination count plateaued for 3 successive periods. Germination was classed as the radicle or plumule visibly emerged from the testa.

3.1.1 Calculations

To calculate the cardinal temperatures first the rate of germination was calculated. This was done by calculating the time in days (d) it took to reach 50% of the final germination of the replicate, using a straight-line method between the two points closest to 50% of the final recorded germination. This was then inverted to give the effective amount of the 50% germination achieved in a day (d⁻¹). These figures were then plotted against temperature to give different cultivar germination rate curves for each temperature. These plots also allowed for a regression to establish a base temperature from the germination rates at lower temperatures, the number of data points used for the regression varied to maximise r² value for each replicate. The same process was done with the highest temperatures to find maximum temperature. Optimum temperature was taken to be the temperature where maximum germination rate was achieved.

3.2 Field Experiment

3.2.1 Locations and Site History

The field experiment was conducted at Ashley Dene, Springston, Canterbury, New Zealand (43°39'11.10"S, 172°19'05.71"E, and 38 m.a.s.l). The soil type is a Lismore silt loam (Landcare

Research, 2013). Full descriptions given by Riddell (1979). The shallow Lismore stony silt loam is well drained with 60-89mm of total available water per metre of soil and a depth to hard soil of 200-450mm (Landcare Research, 2013).

The experimental site was sown into a white clover and perennial ryegrass pasture mix in 2010 and grazed in rotation with the rest of the farm until May 2013. The trial area was prepared with Roundup (a.i. 360 g/l glyphosate) at 2 l/ha and Accelerate (a.i. Organo silicone) surfactant at 100 ml/100 l.

3.2.2 Experimental Design

The experiment was set up in a split plot design with sowing date (21 August, 13 September and 3 October) as the main plot and sowing rate (2, 4 or 6 kg/ha) and plant growth regulators (with or without) making up the plot splits. The plant growth regulator was Cycocel® (a.i. 11.8% chlormequat (2-chlorethyl) trimethylammonium chloride) and was applied at 1 l/ha on 21 October, 31 October and 12 November for the August, September and October sowings respectively. The plots were 23m long and each split being 11m long and all plots being 4.2m wide.

3.2.3 Sowing and Establishment

The plots were sown using an Oyjord cone seeder (coulters spacing 15 cm) from south to north, with sowing depths approximately 1- 1.5 cm. The *Camelina sativa* seeds used for this experiment were Calena and they were treated with Gaucho® at 12 ml/kg and Vitaflo® fungicide at 1 ml/400 g (a.i. 200 g/l carboxin and 200 g/l thiram and 50 g/l ethylene glycol). A post sow herbicide (Roundup a.i. 360 g/l glyphosate at 2l/ha and Magister® a.i. 480 g/L clomazone at 0.3 l/ha) was applied after or within 24 hours of sowing.

3.2.4 Agrichemical Use

Insect damage was noted 10 October and therefore the trial had Attack® insecticide at 1 l/ha (a.i. 25 g/l permethrin plus 475 g/l pirimiphos-methyl) eight days later. Proline fungicide at 800 ml/ha (a.i. 250 g/litre prothioconazole) was applied for *Sclerotinia* control on at mid flower each sowing date on 13 and 27 November and 6 December. The trial was bird netted in December.

3.2.5 Soil fertility

Soil samples to 15 cm depth were taken on 29 May sowing for a quick MAF soil test and results are shown in Table 3.1

Plant N samples were taken at GS30 (start of stem elongation), these were analysed by ground in a mill to pass through a 1 mm stainless steel sieve (Cyclotec Mill, USA). Near infrared spectroscopy (NIR) was used to determine crude protein after a cross calibration was generated between NIR measurements and wet chemistry techniques (Lincoln University Analytical Laboratory Unit). Crude protein was divided by 6.25 to get N%.

Table 3.1 MAF quick soil test results for Ashley Dene to 15 cm depth.

Soil Fertility							
Season	pH	Olsen P	Ca	Mg	K	Na	S
2013-14	5.8	20	8.0	0.86	0.88	0.09	10

Note: Soil test Units Olsen P (mg/L), Ca (me/100g), Mg (me/100g), K (me/100g), Na (me/100g), S (mg/kg)

Table 3.2 Available soil nitrogen (kg/ha) at different depths for Ashley Dene and Plant nitrogen at GS30.

Depth (cm)	2013-14
0-15	167
15-30	77
30-42	68

3.2.6 Measurements

Emergence was measured (where 5 sets of 1m drill rows were counted per plot) for the August sown plots up to 50 days after sowing and up to 40 days for the September sowing and 26 days after the October sowing. Emergence measurements ceased once plant population in the field became difficult to measure due to plant size and were subsequently recorded at 50% flower and final harvest. Growth stage was measured every 4-14 days after emergence measurements ceased.

At 50% flower plants were harvested from each sub plot by hand using secateurs and quadrats (0.4m²/subplot). Plants were counted for each sample and a subsample of 5 plants was measured for height and growth stage. Samples were dissected into sown and weed components before being dried in an oven at 65 °C to a constant weight.

At final harvest 0.4 m²/subplot were harvested, plants were counted and a subsample of 10 plants was measured for height, secondary branching and harvest index. The 10 plants and the remainder of the sample were used to determine total dry matter. Plant samples at final harvest were hung to dry in a warm room until the sample weight was considered constant. Harvest index samples were threshed and cleaned by hand. Plots were harvested by a Winterseiger header (1.5 - 1.6m width). Seed moisture was measured immediately after harvesting at Lincoln University, seed moisture was considered high at heading due to green weed seed contamination, mainly fathen (*Chenopodium album*). Headed subsamples were further cleaned via a Kamas Westrup seed cleaner once seed was considered dry enough to flow through seed cleaner. Seed weight and weed contamination were measured after seed cleaning. The weed contamination was 0.3 – 23.4% and if samples had a weed contamination of >5%, then they were re-cleaned before seed press. The seed yield was adjusted for seed moisture content determined at seed press.

Oils were extracted by cold pressing using a Komet screw press (screw speed 1.5, choke size 4 mm head temperature 80 °C). The cold pressed oil yield was determined after the crude oil was centrifuged and filtered through a 1 µ filter.

Near-infrared spectrometry (NIR) was used to determine oil content which was confirmed by duplicate soxhlet extraction and recalibration of the NIR correlation (Lincoln University Analytical Laboratory Unit). Outliers that hadn't been calibrate were removed.

3.3 Meteorological data

Mean monthly air temperature, total monthly rainfall data, minimum and maximum daily temperatures were all collected from the nearby Broadfields meteorological station (43°62'S, 172°47'E).

The rainfall data for the experiment period was very volatile compared to long term means with an extreme rainfall event occurring in June that caused a delay of sowing and a very wet soil profile. As well as a particularly dry November and January period (Figure 3.1).

The temperature data for the experiment was within normal ranges of the long term mean (Figure 3.1).

3.4 Thermal time

Thermal time was calculated from the meteorological data and the equation $GDD = \sum [(T_{Max} + T_{Min})/2] - T_{Base}$ sourced from McMaster and Wilhelm (1997). Where GDD = Growing Degree Days (°C d), Σ =Sum of, T_{Max} = maximum daily temperature, T_{Min} = minimum daily temperature and T_{base} =the relevant base temperature for the crop. The base temperature established from laboratory experiments was used as the base temperature.

3.5 Statistical Analysis

Data was analysed with Genstat 16 and means were separated by Fisher's protected LSD. All ANOVA tests were done at the 5% level of significance. Sigmaplot 11.0 was also used for graphing and regression analysis.

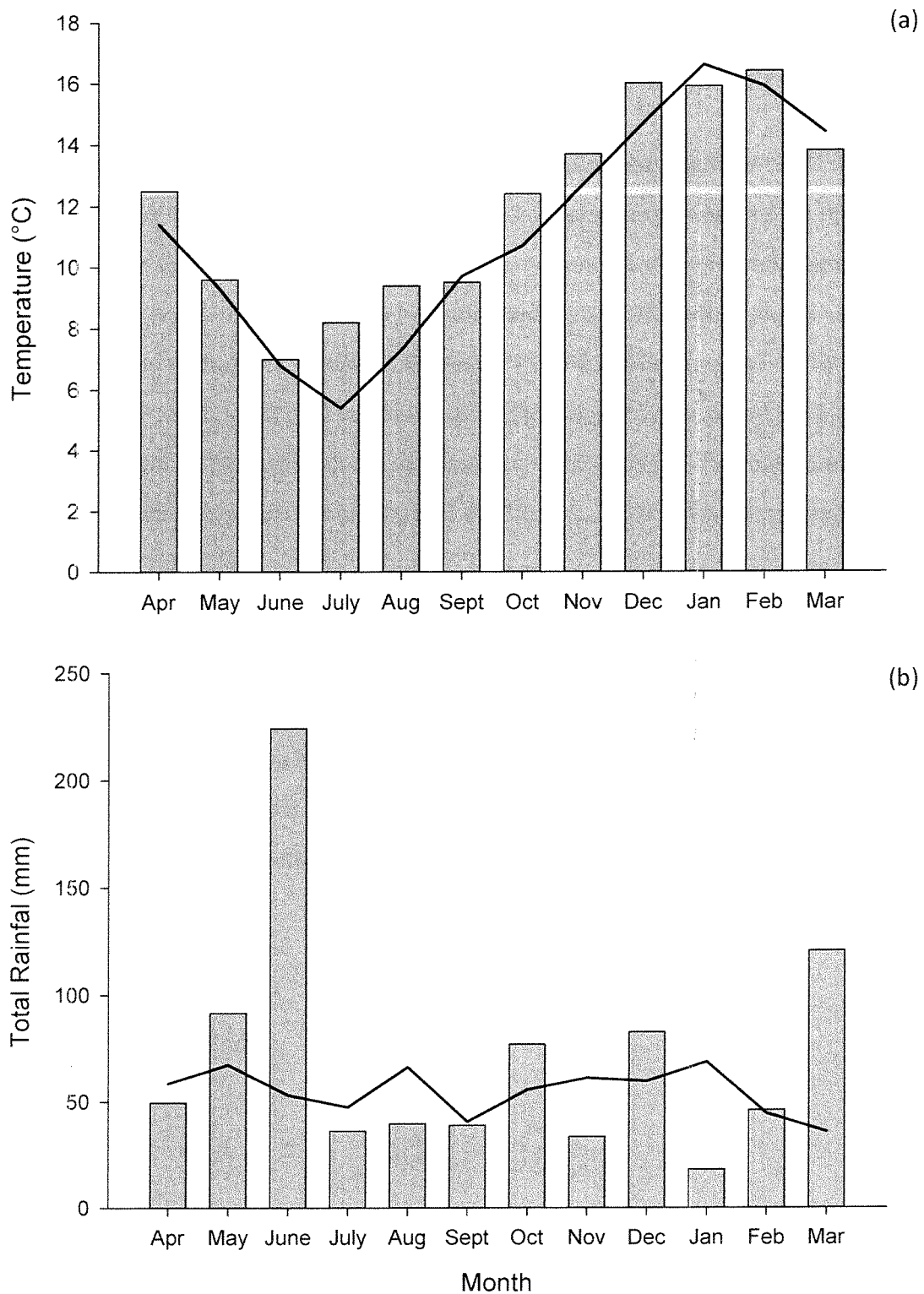


Figure 3.1 The bars are (a) mean monthly temperature ($^{\circ}\text{C}$) and (b) total monthly rainfall (mm) at Broadfields meteorological station for the 2013-2014 growth period. The lines are the long term trends from 1975-2010.

4 RESULTS

4.1 Determination of Cardinal temperatures

To determine the minimum, maximum and optimum temperature of *C. sativa*, germination tests were run on a range of temperatures at 5°C intervals from 5°C to 40°C. All cultivars reached over 90% germination for temperatures 5°C -30°C, with 35°C only reaching 37% for Suneson after 4.5 days and 52% for Calena and 4164 after 2.5 days with no germination occurring at 40°C. Temperatures 20°C, 25°C and 30°C were the fastest to germinate, Suneson and 4164 achieved 90% germination in 3 days while Calena did in 2.5 days. At 15°C, 90% germination was achieved 0.5 days later across all cultivars. At 5°C and 10°C slightly slower germination curves are present but are delayed and do not begin until 2.5 and 5.5 days respectively for Suneson and Calena and 2.5 and 6.5 days respectively for 4164 (Figure. 4.1).

The germination rate was significantly different ($P < 0.001$) between cultivars across the range of temperatures. Calena was the highest germinating with an average of 79.5%, Suneson was the second highest on 77.5% and 4164 the lowest on 75.8% germination. However there was no interaction effect between cultivar and temperature ($P = 0.306$).

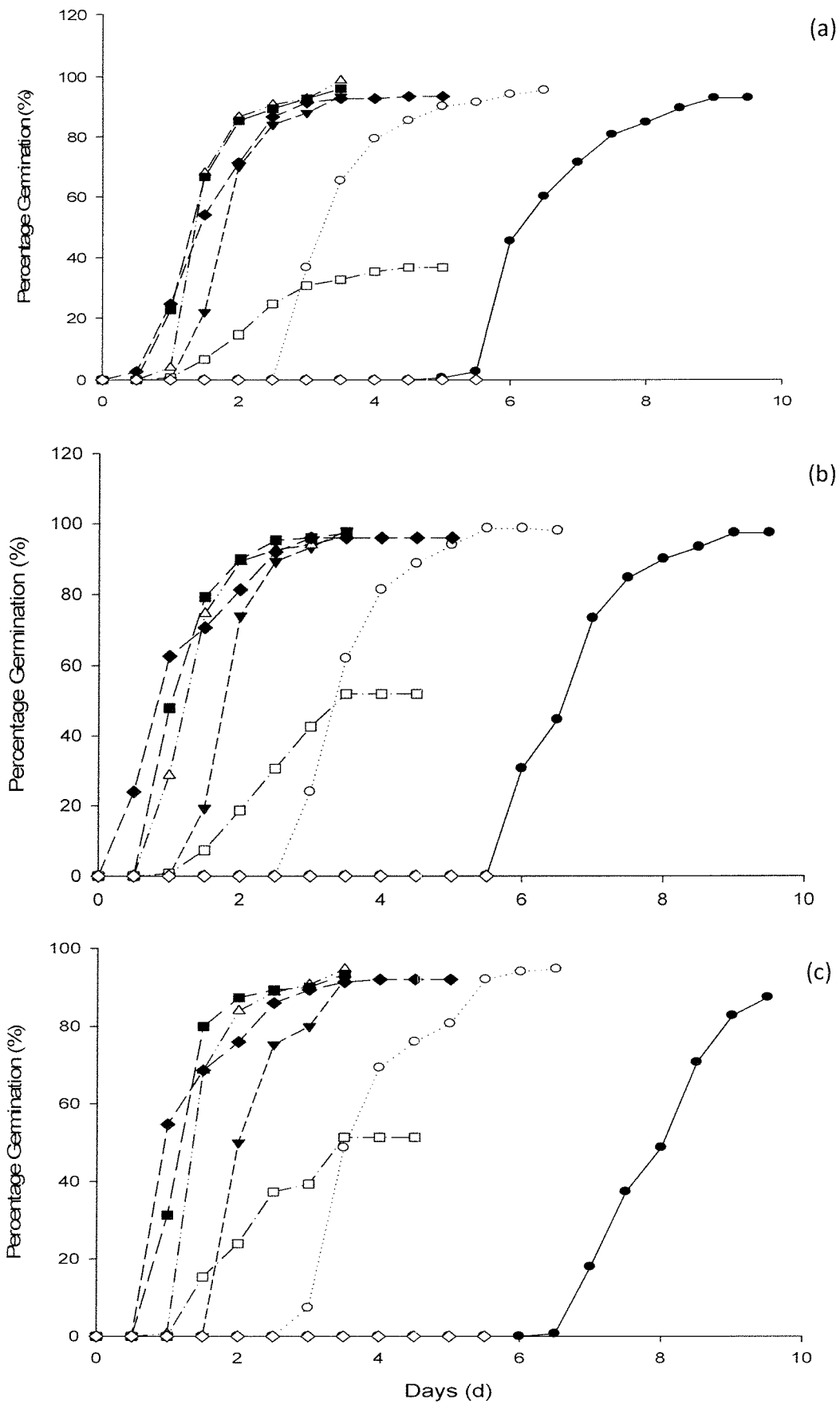


Figure 4.1 Germination rate (% germinated) over time (days) with 8 different temperature treatments: 5°C (■), 10°C (○), 15°C (▼), 20°C (△), 30°C (◆), 35°C (□), 40°C (◇) for three different cultivars, Suneson (a), Calena (b), and 4164 (c).

The time taken to 50% germination (days) was calculated from germination trials for all three cultivars (Figure. 4.1) and this was used to show the rate of germination (days^{-1}). From 5°C to 15°C cultivar 4164 has a significantly lower germination rate, but at 20°C and 25°C the rate was the same as Suneson, as Suneson began to plateau to a maximum of 0.79 d^{-1} between 25°C and 30°C. In contrast 4164 increased to peak at an average rate of 1.06 d^{-1} at 30°C the same as Calena which maintained a significantly higher germination rate than 4164 peaking at 1.24 d^{-1} . All cultivars significantly decreased in germination rate at higher than 35°C. No cultivars germinated at 40°C.

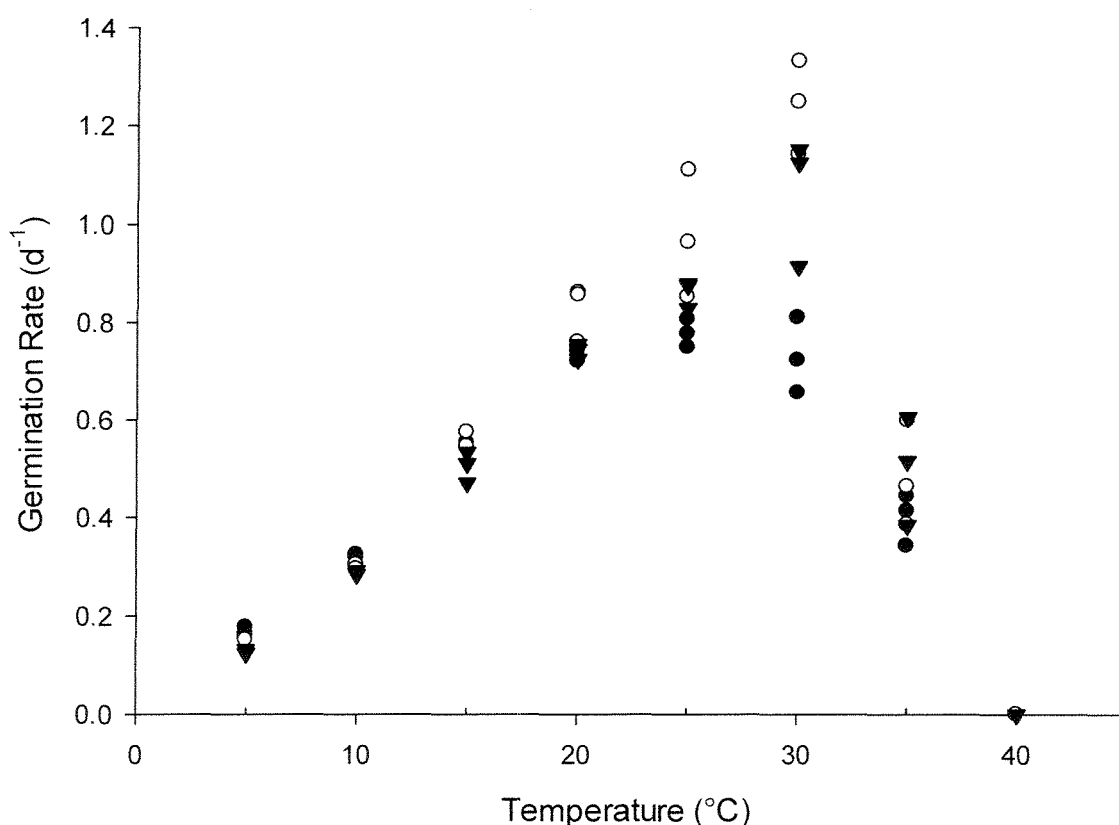


Figure 4.2 Rate to 50% germination (d^{-1}) of *Camelina sativa* under eight different temperatures for three different cultivars, Suneson (●), Calena (○), and 4164 (▼).

A linear regression was plotted against the lower temperature germination rates and used to calculate base temperatures with highest linear r^2 value for each cultivar (first four values for Suneson, first six values for Calena and 4164). There was no significant difference between cultivars for base temperature ($P=0.35$). The base temperatures were therefore averaged and the base temperature across cultivars was $1.66 \pm 0.49^\circ\text{C}$.

The temperature the recorded the highest growth rate (maximum) for each replicate was regarded as the optimum. These optimum temperatures showed no significant difference across cultivars ($P=0.08$). Therefore all optimum temperatures were averaged to give an optimal growth temperature of $28.89 \pm 1.35^{\circ}\text{C}$

Similar to the minimum temperature, a linear regression was plotted against the highest temperature rates to calculate a maximum temperatures from the trend line with highest linear r^2 value. There was no significant difference ($P=0.12$) between the maximum temperatures for each cultivar , the maximum temperatures were therefore averaged and the maximum temperature across cultivars was $40.85 \pm 2.4^{\circ}\text{C}$ slightly above 40°C with a growth rate of 0 d^{-1} .

4.2 Field Experiment

For different sowing rates there was no significant difference in the maximum emergence count. However for the final counts across the all sowing rates there is no significant difference between the first and second sowing dates but the third sowing date is significantly higher than the others. This is also reflected in the percentage survival where the third sowing date is significantly higher than all others sowing dates at 97% or higher across all rates, yet the highest survival for the other sowing dates was 56%, with at 2kg ha⁻¹ sowing date 1 and 2 being insignificantly different and for 4 and 6kg ha⁻¹ being significantly higher at sowing date 2.

The maximum ($P<.001$) and final ($P<.001$) emergence counts were significantly different across sowing rates and increased with increasing sowing rate.

Table 4.1 Average maximum germination count, average final emergence count and average survival from maximum to final count (%) under 3 different sowing rate treatments: 2kg ha⁻¹, 4kg ha⁻¹ and 6kg ha⁻¹ and 3 different sowing date treatments: 21st August 2013, 13th September 2013 and 3rd October 2013 from weekly field measurements at Ashley Dene, Canterbury, New Zealand taken from sowing until 50, 40 and 26 days after sowing respectively.

Sowing Rate (kg ha ⁻¹)	Sowing Date	Maximum Germination Count	Final Germination Count	Survival (%)
2	21/08/2013	12.9	4.8	37
	13/09/2013	13.3	4.9	37
	3/10/2013	16	15.6	96
	LSD	NS	2	9.3
4	21/08/2013	27	7.6	28
	13/09/2013	23	12.5	55.5
	3/10/2013	33.9	33	97
	LSD	NS	5.7	16
6	21/08/2013	37.4	11.3	31
	13/09/2013	36.8	16	44
	3/10/2013	45.5	44	97
	LSD	NS	6.7	6.9

NS not significant. LSD values are for significant factor at 0.05 significance.

At 50% flowering sowing date 3 had significantly ($p=0.007$) less weeds than sowing date 1 and 2 with 261kgDM/ha compared to 484kgDM/ha and 480kgDM/ha respectively. The lowest sowing rate 2kg ha⁻¹ also had significantly ($p=0.002$) more weeds at 55kgDM/ha compared to 395 kgDM/ha and 255kgDM/ha for 4kg ha⁻¹ and 6kg ha⁻¹ respectively.

At harvest sowing date 1 had significantly ($p=0.009$) taller plants at 47cm compared to sowing dates 2 and 3 with 41.4cm and 42.4cm tall respectively.

Table 4.2 Average Camelina height (cm), total biomass (kgDM ha⁻¹) and seed yield (kg ha⁻¹) under 2 different plant growth regulator rates 0 L ha⁻¹, 1 L ha⁻¹ from measurements taken at final harvest which occurred on 15th January 2014 for sowing date 1 and 28th January for sowing date 2 and 3 at Ashley Dene, Canterbury, New Zealand.

		Height (cm)	Total Biomass (kgDM ha ⁻¹)	Seed Yield (kgDM ha ⁻¹)
Plant Growth	0 L ha ⁻¹	55.68	3697	923
Regulator	1 L ha ⁻¹	52.97	3864	915
Cycocel®	LSD	2.65	NS	NS

NS not significant. LSD values are for significant factors at 0.05 significance.

The amount of secondary branches formed was significantly ($P<0.001$) greater for sowing date one and two with an average of 6.25 and 5.44 compared to 3.82 for the third sowing date. The sowing rate was also significant ($P<0.001$) with 4kg ha⁻¹ and 6kg ha⁻¹ with 4.71 and 4.05 secondary braches per plant compared to 6.67 for 2kg ha⁻¹.

Table 4.3 Camelina plant nitrogen levels (%) across 3 different sowing date treatments: 21st August 2013, 13th September 2013 and 3rd October 2013, Taken from field trials at growth stage 30 at Ashley Dene, Canterbury, New Zealand.

Sowing date	Plant Nitrogen (%)
21/8/2013	5.11
13/9/2013	4.75
3/10/2013	4.99

Table 4.4 Average Camelina plant density (plants m⁻²), Camelina total biomass (kgDM ha⁻¹), Seed Yield (kg ha⁻¹), harvest index and thousand seed weight (g) under 3 different sowing rate treatments: 2kg ha⁻¹, 4kg ha⁻¹ and 6kg ha⁻¹ and 3 different sowing date treatments: 21st August 2013, 13th September 2013 and 3rd October 2013 and their interaction, measurements taken at final harvest which occurred on 15th January 2014 for sowing date 1 and 28th January for sowing date 2 and 3 at Ashley Dene, Canterbury, New Zealand.

			Density	Total	Seed	Harvest	TSW
			(plants	Biomass	Yield	Index	(g)
			m ⁻²)	(kgDM	(kg ha ⁻¹)		
				ha ⁻¹)			
Sowing	21/08/2013		98	4171	883	33.9	1.261
Date							
	13/09/2013		126.9	3252	577	36.5	1.314
	3/10/2013		300.7	3786	1211	42.1	1.446
	LSD		41.59	553.5	117.2	3.7	0.0291
Sowing	2		104.2	3669	744	37.2	1.34
Rate	4		183.6	3659	945	37.4	1.35
(kg ha ⁻¹)	6		251	4014	1068	38.1	1.34
	LSD		37.62	NS	106.1	NS	NS
Sowing	21/08/2013	2	64.4	3916	638	32.8	1.19
Date x		4	102.8	4226	897	34.5	1.29
Sowing		6	126.9	4372	1115	34.5	1.31
Rate	13/09/2013	2	66.7	2843	397	39.3	1.4
(kg ha ⁻¹)		4	131.2	3036	554	33.9	1.29
		6	182.9	3877	779	36.2	1.26
	3/10/2013	2	172.2	4041	1110	40.2	1.44
		4	303.8	3559	1285	43	1.45
		6	426.3	3759	1238	43	1.44
		LSD	72.04	NS	NS	NS	NS
NS not significant. LSD values are for significant factors at 0.05 significance.							

As Table 4.4 shows density is significantly different across both sowing date ($p<.001$) and sowing rate ($p<.001$) as well as the interaction of both ($p=.002$). Density increased significantly at later sowing dates from 98 plants m^{-2} to 126.9 plants m^{-2} to 300.7 plants m^{-2} respectively. Density also increased with sowing rate from 104 plants m^{-2} at 2kg ha^{-1} to 183.6 plants m^{-2} at 4kg ha^{-1} to 251 plants m^{-2} at 6kg ha^{-1} .

Total Biomass produced was significantly different for sowing date ($p=.004$) but not for sowing rate ($p=.2777$). Sowing date one had the highest biomass with 4171kgDM ha^{-1} , with sowing date two having lowest biomass at 3252kgDM ha^{-1} and sowing date three having 3786kgDM ha^{-1} .

Total seed yield is significant for both sowing date ($p<.001$) and sowing rate ($p<.001$). Sowing date 3 is the largest with 1211kgDM ha^{-1} followed by sowing date 3 with 883kg ha^{-1} and again with the lowest value sowing date 2 with 577kgDM ha^{-1} . For sowing rate seed yield significantly increases with sowing rate with 744kgDM ha^{-1} , 945kgDM ha^{-1} and 1068kgDM ha^{-1} for 2kg ha^{-1} , 4kg ha^{-1} and 6kg ha^{-1} sowing rates respectively.

Harvest index shows the proportion of the plant that is the desired harvestable product, in this case it is only significant for sowing date ($p<0.001$) with both sowing date one and two on 33.92% and 36.48% being significantly lower than sowing date three on 38.09%.

TSW is significantly different across sowing dates with seed weight increasing with later sowing dates from 1.261 to 1.413 to 1.446 for sowing dates 1, 2 and 3 respectively.

There was also a significantly different ($P<.001$) number of seeds per hectare with sowing date three having 840,000, sowing date one having 700,000 and sowing date two having 450,000 seeds, nearly half as many as sowing date 3.

Seed moisture content was significantly ($P<0.001$) higher for the first sowing date on 8.2% than sowing date 2 and 3 on 7.75% and 7.4% respectively.

The fat content of the seeds is significantly different for both sowing date ($p=.012$) and sowing rate ($p=.042$). For sowing date sowing date 1 had significantly lower fat content of

9.5% compared to 9.66% for sowing date 3 while sowing date two was insignificantly different from either on 9.53%. Lower sowing rates of 2kg ha⁻¹ and 4kg ha⁻¹ were also significantly higher both on 9.6% compared to 9.45%.

Table 4.5 Average calendar days (d) and growing degree days (°C d) from sowing to 100% emergence (S-E), emergence to 50% stem elongation (E-SE), stem elongation to 50% flowering (SE-F), flowering to harvest (F-H and emergence to harvest (E-H). Growth stage data came from growth stage measurements taken every 4-14 days after emergence measurements ceased at Ashley Dene, Canterbury, New Zealand. The base temperature used was based on results from section 4.1.

	Sowing Date	Calendar Days (d)	Growing Degree Days (°C d)
S-E	21/08/2013	17.7	148
	13/09/2013	19	191
	3/10/2013	23	249
	LSD	1.6	7.2
E-SE	21/08/2013	40	383
	13/09/2013	32	320
	3/10/2013	17	211
	LSD	1.9	18.5
SE-F	21/08/2013	48	369
	13/09/2013	39.8	308
	3/10/2013	42.8	282
	LSD	2.4	19.3
F-H	21/08/2013	98.6	859
	13/09/2013	97.2	932
	3/10/2013	74	818
	LSD	2.4	18.4
E-H	21/08/2013	187	1611
	13/09/2013	169	1560
	3/10/2013	134	1311
	LSD	1.6	14.5

Table 4.3 shows the time between development stages in both calendar days and growing degree days. ANOVA's performed all show significance ($p < .001$) only S-E and F-H for sow date 1 are not significantly different. The total time from emergence to harvest decreases with later sowing dates for both calendar days and growing degree days. This is consistent across E- SE and SE- F stages for GDD and E- SE and F-H for CD, however sowing date 2 is the longest for GDD for F-H and shortest for CD for SE-F. In contrast to those trends for S-E there is a significant increase for both CD and GDD with later sowing dates.

Thermal time between growth staged appears to be negatively correlated with daylength, particularly for sowing to emergence ($r^2=0.76$), emergence to stem elongation ($r^2=0.85$) and stem elongation to flowering ($r^2=0.64$). Which indicates day length may play a significant role in development.

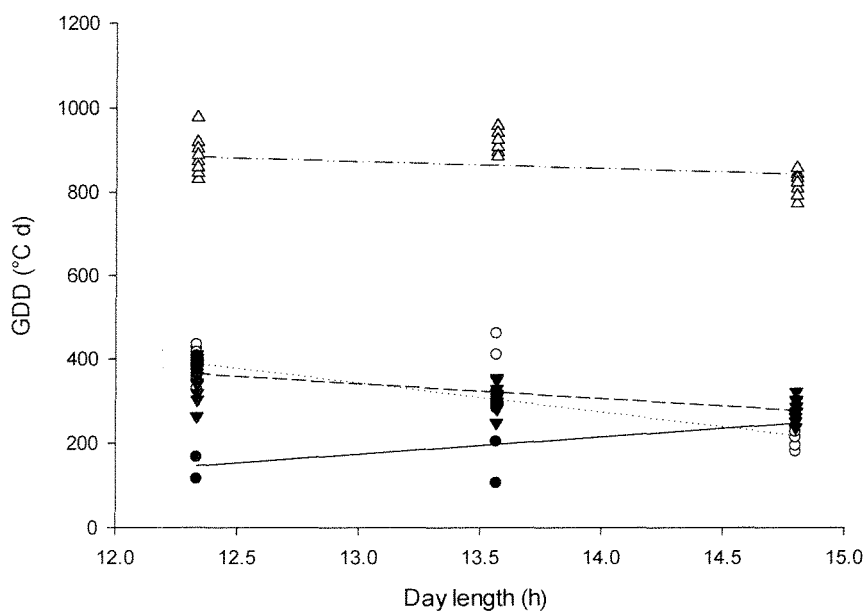


Figure 4.3 Thermal time between growth stages ($^{\circ}\text{C d}$) against day length at 100% emergence (h) for four different growth stages: Sowing to 100% emergence (●) ($r^2=0.76$), 100% emergence to 50% stem elongation (○) ($r^2=0.85$), 50% stem elongation to 50% flowering (▼) ($r^2=0.64$) and 50% flowering to harvest (Δ) ($r^2=0.11$).

5 DISCUSSION

The objectives of this study was to analyse how *Camelina sativa* grows and develops in New Zealand conditions and the effect of agronomic management on its growth and development. Specifically the effect of sowing date, sowing rate, plant growth regulators and cardinal temperatures were studied. This chapter discusses results in relation to previous *Camelina* experiments, or where data is not available, close relatives such as oilseed rape.

5.1 Cardinal Temperatures

5.1.1 Base Temperature

Base temperature was found to be the same across cultivars and was found to be $1.66 \pm 0.49^{\circ}\text{C}$. This result was different from Allen, Vigil, and Jabro (2014) that found the base temperatures to be significantly different between some cultivars including Calena with a base temperature of -0.57°C and Suneson with -0.98°C . This could have been due to the higher concentration of trials at lower temperatures including one at 0°C which germinated after nearly 70 days giving more significant results at a lower temperature or the use of a soil medium when incubated which they proved increased base temperature by acting as an insulator with increased sowing depth. Previously a relatively arbitrary base temperature of 5°C was used when calculating thermal time (Blackshaw et al., 2011; R. W. Gesch, 2014) for *Camelina*.

5.1.2 Optimum Temperature

The optimum temperature was $28.9 \pm 1.35^{\circ}\text{C}$ as was not significantly different across cultivars. This is consistent with V. Russo et al. (2010) which found the shortest time frame for maximum germination in *Camelina* was between 16 and 32°C . This also lines up with Carmo-Silva and Salvucci (2012) found the optimum temperature of photosynthesis for *Camelina* was about 30°C .

5.1.3 Maximum Temperature

The maximum temperature of growth was extrapolated to be $40.85 \pm 2.4^{\circ}\text{C}$ which was in line with no germination being achieved at 40°C . There is no published data on the maximum

growth temperature of Camelina but V. Russo et al. (2010) found lower germination at 32°C in line with the lower recorded germination recorded at 35°C.

5.2 Sowing Date

5.2.1 Development Time

Time between growth stages and to harvest decreased with later sowing dates as expected and found by R. W. Gesch (2014). Consequently days after sowing is not a good predictor of growth stage.

5.2.2 Thermal Time

Growing Degree Days (GDD) are significantly different across all intervals for different sowing dates which indicates they are not an accurate predictor of the development of Camelina. This is also in keeping with results from R. W. Gesch (2014) which shows a significant difference of GDD across a range of different sowing dates for Camelina. As Figure 4.3 shows there is a negative correlation between growing degree days and day length at emergence for all stages except sowing to emergence, this indicates that there is a day length effect on plant development and that the thermal time requirement may decrease with increasing day length. This is similar to the regression for thermal time to 50% flowering and day length at 50% found by Burton et al. (2008) for oilseed rape, a close relative to Camelina. Surprisingly sowing to emergence has a positive correlation but as day length cannot effect emergence is therefore caused by other factors.

5.2.3 Plant Population

There are some big differences in emergence data between sowing dates. As table 4.1 shows there is a significant difference of time between sowing and 100% emergence for different sowing dates. This interval actually gets longer with later sowing dates despite there also be higher temperatures and therefore thermal time. This is likely attributable to errors in sowing depth, in the early sowing dates the wet soil conditions made planting difficult and may have resulted in shallow sowing depths. This could therefore mean that the last sowing date was in fact planted deeper which, as Lamb and Johnson (2004) found for oilseed rape, would mean a longer time to emergence.

The maximum germination counts were not significantly different when the same sowing rates were compared across sowing dates (Table 4.1). This shows that plant numbers were

not significantly reduced due to different sowing depths or human errors in planting and equal germination appeared to occur. However Table 4.1 also shows that the final emergence count taken was relatively unchanged from the maximum with survival rates of over 96%, compared to maximum survival of sowing date 1 and 2 of 37% and 56% respectively. While this may be effected from the stopping emergence counts earlier for sowing date 3, the lower plant numbers are also evident in density (plants m^{-2}) at harvest with sowing date one and two being not significantly different from each other but having less than half the number of plants for the comparable sowing rates for sowing date 3, the 6kg/ha sowing rate for sowing date one and two even had similar plant numbers to 2kg/ha at sowing date 3.

This may have been caused by herbicides glyphosate or clomazone which were applied after sowing. Herbicide bleaching, which is the characteristic of whitening of leaves was noticed on the developing plants especially for sowing date one and two. Clomazone is the active ingredient in Magistar and has been shown to have the potential to cause injury to soybean plants, however the environmental conditions have a significant effect on the severity of the injury (Hager, 2014). Plants often stop injury by metabolising the active ingredient to a non-phytotoxic form, therefore lower photosynthesis and plant stressors such as cold or wet conditions often result in higher plant death (Hager, 2014). It therefore may have been the interaction of environmental stressors and this herbicide that caused the high post emergence plant deaths. Sowing date one and two had 6 and 3 periods below the base temperature found in Section 4.1 while the third sowing date had none, also the large rainfall in June left the soil very wet especially for sowing date one and to a lesser extent two. There was also a minimum temperature increase of 0.9°C with each sowing date and an average temperature increase of approximately 0.5°C . This therefore may have reduced plant stress and increased the plants ability to metabolise the active ingredient therefore decreasing plant death.

5.2.4 Seed Yields

Total seed yield was highest for sowing date three at 1211 kg ha^{-1} , then sowing date one at 883 kg ha^{-1} , followed by sowing date two at 577 kg ha^{-1} . While normally yields would be expected to decrease with later spring sowing dates as Berti et al. (2011), R. W. Gesch (2014)

and Fasi et al. (2012) however given the significantly higher plant populations for sowing date three, it seems logical that it would have the greatest yield. Similar to the literature sowing date two has lower yields than sowing date one as it developed faster in 169 days compared to 187 (Table 4.4). Sowing date 1 also had a higher number of branches per plant which Urbaniak et al. (2008) found there was a high correlation between number of branches per plant and the number of pods per plant which was also highly correlated with seed yield. Seed yields for sowing date one and two could also have been more effected by bird damage before bird netting was applied as damage tends to be greater for earlier sowing dates as shown by A. Pavlista et al. (2011).

5.2.5 Thousand Seed Weight

Thousand seed weight (TSW) increases with increasing sowing date, which is in contrast to Berti et al. (2011) which showed higher TSW for earlier sowing dates. However this may have been impacted by the difference in density between sowing dates with earlier sowing dates having significantly lower densities (Table 4.4) Agegenehu and Honermeier (1997) and KONČIUS and KARČAUSKIENĖ (2010) showed a negative correlation between thousand seed weight and density, and similar to this experiment lower densities resulted in more branches per plant which correlates with a higher number of seeds in each pod, which has been proven to result in lower thousand seed weights (Sabaghnia, Dehghani, Alizadeh, & Mohghaddam, 2010) which would be consistent with these results.

5.2.6 Weeds

Weed biomass was lowest at sowing date three consistent with results from Berti et al. (2011) and Fasi et al. (2012) and consistent with it being highest density sowing date, however sowing date one and two are not significantly different contrary to literature that suggests sowing date two would have larger weed population than normally expected. Later sowing dates tend to mean lower weed populations as seeds in the weed bank may germinate before sowing and be killed off during sowing and planting (Chauhan, Singh, & Mahajan, 2012). However as sowing date two is equal to one there is likely factors causing a higher comparable weed biomass for sowing date two, this may be due to more light getting through the canopy to the weeds in sowing date two, which could have been caused by a difference in canopy between sowing dates. While sowing date one has a similar density in plants per metre squared this does not take into account the difference in secondary branch

numbers which are higher in sowing date one than two and may therefore mean there is greater light interception causing lower than expected weed biomass. Crop biomass is also higher in sowing date one which may be consistent with Lemerle, Luckett, Koetz, and Wu (2012) which showed crop biomass yields were negatively correlated to weed population in canola.

5.2.7 Camelina Biomass

Biomass was highest at sowing dates one and three with sowing date two being significantly lower. Usually biomass would decrease with later spring sowing dates as shown by Berti et al. (2011) and Fasi et al. (2012). However, given the plant population results and seed yield for the different sowing dates it would be consistent to see sowing date 3 with the highest biomass. However sowing date one has a similar biomass which is likely the result of increased compensatory growth from sowing date one in response to low density and early plant stressors. This is shown by the higher number of secondary branches which was nearly double that of sowing date three, this is also consistent with findings from Urbaniak et al. (2008) which found increased secondary branch numbers were likely a result of compensatory growth. Compensatory growth was likely lower for sowing date two due to the lower plant deaths and the less time to produce biomass meaning lower compensatory growth for the lower plant density, however there were more secondary branches for sowing date two than three indicating some compensatory growth occurred.

5.2.8 Oil Content

Seed oil content was lower for sowing date one than sowing date three but sowing date two was not significantly different from either. The difference in seed oil content is likely environmental as Berti et al. (2011) found that sowing date had little effect on oil content. Average temperatures and rainfall from seed development to harvest were lowest for sowing date one and increased with later the later sowing dates. This is in contrast to Fasi et al. (2012) and (R. W. Gesch, 2014) where oil content decreased with later sowing dates, however in that trial rainfall decreased with later sowing dates, this therefore points to an effect from rainfall, this could be due to positive correlation between oil content and available water or this could be because water was a limiting factor during early seed development for sowing date one with less than 2mm of rainfall in the first two weeks of seed development.

5.3 Sowing Rate

5.3.1 Density

Sowing rate had a significant effect on density which increased with higher sowing rates. This is what you would expect and is consistent with Urbaniak et al. (2008) and Agegenehu and Honermeier (1997).

5.3.2 Seed Yield

Seed yields increased with increasing sowing rates consistent with Agegenehu and Honermeier (1997) and KONČIUS and KARČAUSKIENĖ (2010) which showed increasing yields at sowing rates comparable to those in this trial before a decline in yield.

5.4 PGR's

There was not any significant lodging in the crop, which would have been most likely to cause a significant difference from plant growth regulator application. The lack of lodging may be because of the relatively low soil fertility and no nitrogen fertiliser applications. Plant growth regulators(PGR's) did not have an effect on yield or biomass which is similar to Armstrong and Nicol (1991) found that Cycocel was not significantly different from no plant growth regulator in an oilseed rape crop across seed yield, height and biomass . However there was a decrease in plant height associated with PGR application which is similar to Riffkin et al. (2012) which found Cycocel had no effect on oilseed rape yield in the absence of lodging but in some instances had an effect on height, branching.

6 GENERAL DISCUSSION AND CONCLUSIONS

The objectives of this study was to analyse how *Camelina sativa* grows and develops in New Zealand conditions and the effect of agronomic management on its growth and development. Specifically the effect of sowing date, sowing rate, plant growth regulators and cardinal temperatures were studied.

6.1 General Discussion

There were some interesting results in this experiment especially relating to sowing date. The most significant effect was the change in plant population post emergence, which saw significantly lower survival of sowing date one and two seedlings (Table 4.1). This was likely caused by a post sowing herbicide and cold interaction resulting in plant death. This therefore made it difficult to draw any conclusions about the effect of different sowing dates on *Camelina* in New Zealand. This does however highlight how sensitive *Camelina* is to herbicide damage. And the need to be very careful about using any herbicides with the crop. However as both sowing date one and two appear to have been effected by herbicide damage, the expected effects of later sowing date are seen between these two treatments with sowing date 3 often out performing what was the other sowing dates due to the lack of seedling death and the consequent results such as decreased density and increased secondary branches. For example there was decreasing biomass and seed yield with later sowing date between sowing date one and two, despite sowing date one being more significantly damaged across several treatments. This indicates that an early spring sowing date would be the optimum sowing date for higher seed yields and biomass given normal conditions.

The lack of lodging was also another interesting result, despite there being differences in nitrogen levels between plants there was no lodging which indicates that as *Camelina* is a crop targeted at marginal soils lodging would not be an issue unless significant nitrogen was applied. Higher levels of nitrogen have also been identified as a possible cause of lower oil content, while more research needs to be done on this, it indicates nitrogen application may only be necessary when it is significantly restricting plant growth. It also indicates that plant growth regulators are not likely to be needed in normal conditions for *Camelina*.

Sowing rate treatments were significantly affected by post emergence deaths at sowing dates one and two and consequently sowing date three is the only one that is truly representative of the original sowing rate. This therefore makes it difficult to make any definite conclusions regarding optimal sowing rate for Camelina and while sowing rate 4kg ha⁻¹ is the highest for sowing date three it is not significantly different. Although there is a significant effect of sowing rate on seed yield the results include sowing date one and two which make the average not representative of the sowing rate in normal conditions. There does however appear to be a greater ability to compensate for lower sowing rate at earlier sowing dates and therefore ideal sowing rate probably increases with sowing date. Sowing date also appears to have a greater effect on total biomass than sowing rate does, this is especially noticeable when sowing date one has higher biomass yields than sowing date three, despite having the equivalent of significantly lower sowing rates.

6.2 Conclusions

- Sowing date one would have the highest seed yields and biomass in normal conditions.
- Lodging is not a significant issue in Camelina and plant growth regulators are not required.
- Camelina is very sensitive to herbicide applications, especially in plant stressing conditions.
- Sowing rate for maximum seed yield will increase with later sowing dates.
- Camelina is affected by day length and thermal requirement decreases with increasing day length.
- Camelina has a low nitrogen requirement and nitrogen inputs should only be used when nitrogen is very low.
- The sowing date had a bigger impact on biomass than sowing rate did.

7 REFERENCES

- Abramovič, H., Butinar, B., & Nikolič, V. (2007). Changes occurring in phenolic content, tocopherol composition and oxidative stability of *Camelina sativa* oil during storage. *Food chemistry*, 104(3), 903-909.
- Agegenehu, M., & Honermeier, B. (1997). Effects of seeding rates and nitrogen fertilization on seed yield, seed quality and yield components of false flax. *Die Bodenkultur*, 48(1), 15-20.
- Akk, E., & Ilumäe, E. (2005). Possibilities of growing *Camelina sativa* in ecological cultivation. *Saku, Estonia*, 28-33.
- Allen, B. L., Vigil, M. F., & Jabro, J. D. (2014). *Camelina* Growing Degree Hour and Base Temperature Requirements. *Agron. J.*, 106(3), 940-944. doi: 10.2134/agronj13.0469
- Andersson, C., Brimer, L., Cottrill, B., Fink-Gremmels, J., Jaroszewski, J., & Sørensen, H. (2008). Glucosinolates as undesirable substances in animal feed: scientific opinion of the panel on contaminants in the food chain. *The EFSA Journal*(590).
- Angelini, L. G., Moscheni, E., Colonna, G., Belloni, P., & Bonari, E. (1997). Variation in agronomic characteristics and seed oil composition of new oilseed crops in central Italy. *Industrial crops and Products*, 6(3), 313-323.
- Armstrong, E., & Nicol, H. (1991). Reducing height and lodging in rapeseed with growth regulators. *Animal Production Science*, 31(2), 245-250.
- Bassam, N. E. (2013). *Energy plant species: their use and impact on environment and development*: Routledge.
- Berti, M., Wilckens, R., Fischer, S., Solis, A., & Johnson, B. (2011). Seeding date influence on camelina seed yield, yield components, and oil content in Chile. *Industrial Crops and Products*, 34(2), 1358-1365.

- Blackshaw, R., Johnson, E., Gan, Y., May, W., McAndrew, D., Barthet, V., . . . Wispinski, D. (2011). Alternative oilseed crops for biodiesel feedstock on the Canadian prairies. *Canadian Journal of Plant Science*, 91(5), 889-896.
- Boddiger, D. (2007). Boosting biofuel crops could threaten food security. *The Lancet*, 370(9591), 923-924.
- Büchsen-schütz-Nothdurft, A., Schuster, A., & Friedt, W. (1998). Breeding for modified fatty acid composition via experimental mutagenesis in *Camelina sativa* (L.) Cz. *Industrial crops and products*, 7(2), 291-295.
- Burton, W., Flood, R., Norton, R., Field, B., Potts, D., Robertson, M., & Salisbury, P. (2008). Identification of variability in phenological responses in canola-quality *Brassica juncea* for utilisation in Australian breeding programs. *Crop and Pasture Science*, 59(9), 874-881.
- Cai, X., Zhang, X., & Wang, D. (2010). Land availability for biofuel production. *Environmental science & technology*, 45(1), 334-339.
- Carmo-Silva, A. E., & Salvucci, M. (2012). The temperature response of CO₂ assimilation, photochemical activities and Rubisco activation in *Camelina sativa*, a potential bioenergy crop with limited capacity for acclimation to heat stress. *Planta*, 236(5), 1433-1445. doi: 10.1007/s00425-012-1691-1
- Chauhan, B. S., Singh, R. G., & Mahajan, G. (2012). Ecology and management of weeds under conservation agriculture: a review. *Crop Protection*, 38, 57-65.
- Ciubota-Rosie, C., Ruiz, J. R., Ramos, M. J., & Pérez, Á. (2013). Biodiesel from *Camelina sativa*: A comprehensive characterisation. *Fuel*, 105, 572-577.
- Davis, P. B. (2010). *The invasion potential and competitive ability of Camelina sativa* (L.) Crantz (*camelina*) in rangeland ecosystems. Montana State University-Bozeman, College of Agriculture.

Ehrensing, D. T., & Guy, S. O. (2008). *Camelina Oilseed Crops*.

http://extension.oregonstate.edu/gilliam/sites/default/files/Camelina_em8953-e.pdf: Oregon State University.

Fasi, V., Martin, R., Smallfield, B., & McKenzie, B. (2012). Sowing date effects on timing of growth stages, yield and oil content of potential biodiesel crops. *Agronomy New Zealand*, 42, 33-42.

Fleenor, R. (2011). Plant Guide for Camelina. *Plant Guides*.

Francki, M., Ghamkhar, K., Croser, J., Aryamanesh, N., Campbell, M., Kon'kova, N., & Francis, C. (2010). Camelina (*Camelina sativa* (L.) Crantz) as an alternative oilseed: molecular and ecogeographic analyses. *Genome*, 53(7), 558-567.

Fröhlich, A., & Rice, B. (2005). Evaluation of *Camelina sativa* oil as a feedstock for biodiesel production. *Industrial Crops and Products*, 21(1), 25-31.

Gan, Y., Malhi, S., Brandt, S., & McDonald, C. (2008). Assessment of seed shattering resistance and yield loss in five oilseed crops. *Canadian Journal of plant science*, 88(1), 267-270.

Gehringer, A., Friedt, W., Lühs, W., & Snowdon, R. (2010). I. Publication. *Development of camelina (Camelina sativa Crtz.) genotypes and winter rapeseed (Brassica napus L.) hybrids for marginal locations*, 15.

Gesch, R., & Archer, D. (2013). Double-cropping with winter camelina in the northern Corn Belt to produce fuel and food. *Industrial Crops and Products*, 44, 718-725.

Gesch, R., & Cermak, S. (2011). Sowing date and tillage effects on fall-seeded camelina in the northern corn belt. *Agronomy journal*, 103(4), 980-987.

Gesch, R. W. (2014). Influence of genotype and sowing date on camelina growth and yield in the north central US. *Industrial Crops and Products*, 54, 209-215.

- Gugel, R., & Falk, K. (2006). Agronomic and seed quality evaluation of *Camelina sativa* in western Canada. *Canadian journal of plant science*, 86(4), 1047-1058.
- Hager, A. (2014). Soybean injury from soil-applied herbicides. *IL Soy Advisor*. Retrieved July 06, 2014
- Hunter, J., & Roth, G. (2010). *Camelina Production and Potential in Pennsylvania. Penn State College of Agricultural Sciences*.
- Johnson, E. N. (2011). Agronomy of *Camelina sativa* and *Brassica carinata*.
- KONČIUS, D., & KARČAUSKIENĖ, D. (2010). The effect of nitrogen fertilisers, sowing time and seed rate on the productivity of *Camelina sativa*. *Žemdirbystė Agric.(Lithuania)*, 97, 4.
- Korsrud, G., Keith, M., & Bell, J. (1978). A comparison of the nutritional value of crambe and camelina seed meals with egg and casein. *Canadian Journal of Animal Science*, 58(3), 493-499.
- Lamb, K. E., & Johnson, B. L. (2004). Seed Size and Seeding Depth Influence on Canola Emergence and Performance in the Northern Great Plains. *Agron. J.*, 96(2), 454-461. doi: 10.2134/agronj2004.4540
- Landcare Research. (2013). S-map Online. from Landcare Research
- Lemerle, D., Luckett, D., Koetz, E., & Wu, H. (2012). Canola (*Brassica napus*) competition for weed management. *Pak J Weed Sci Res*, 18, 327-332.
- Marquard, R., & Kuhlmann, H. (1986). Investigations of productive capacity and seed quality of linseed dodder (*Camelina sativa* Crtz). *Fette Seifen Anstrichmittel*, 88(7), 245-249.
- McKenzie, B., Smallfield, B., Fasi, V., & Martin, R. (2011). Possible species for the production of biodiesel on marginal land. *Agronomy New Zealand*, 41, 97-107.
- McMaster, G. S., & Wilhelm, W. (1997). Growing degree-days: one equation, two interpretations. *Agricultural and Forest Meteorology*, 87(4), 291-300.

- Ministry of Economic Development. (2008). Liquid Fuel Use in New Zealand. In M. Rosevear (Ed.). <http://www.med.govt.nz/sectors-industries/energy/pdf-docs-library/energy-data-and-modelling/technical-papers/liquid-fuel-use.pdf>: New Zealand Government.
- Moser, B. R., & Vaughn, S. F. (2010). Evaluation of alkyl esters from *Camelina sativa* oil as biodiesel and as blend components in ultra low-sulfur diesel fuel. *Bioresource technology*, 101(2), 646-653.
- Muppaneni, T., Reddy, H. K., Patil, P. D., Dailey, P., Aday, C., & Deng, S. (2012). Ethanolysis of camelina oil under supercritical condition with hexane as a co-solvent. *Applied Energy*, 94, 84-88.
- NZFSA. (2009). Glucosinolates Information Sheet. Retrieved October 01, 2013
- Paulsen, H. M., Wichmann, V., Schuemann, U., & Richter, B. (2011). Use of straight vegetable oil mixtures of rape and camelina as on farm fuels in agriculture. *Biomass and Bioenergy*, 35(9), 4015-4024.
- Pavlista, A., Isbell, T., Baltensperger, D., & Hergert, G. (2011). Planting date and development of spring-seeded irrigated canola, brown mustard and camelina. *Industrial crops and products*, 33(2), 451-456.
- Pavlista, A. D., Baltensperger, D. D., Isbell, T. A., & Hergert, G. W. (2012). Comparative growth of spring-planted canola, brown mustard and camelina. *Industrial Crops and Products*, 36(1), 9-13.
- Peiretti, P., & Meineri, G. (2007). Fatty acids, chemical composition and organic matter digestibility of seeds and vegetative parts of false flax (*Camelina sativa* L.) after different lengths of growth. *Animal feed science and technology*, 133(3), 341-350.
- Riddell, D. (1979). *Investigation of physical and hydrological characteristics of the Lismore stony silt loam*. Lincoln College, University of Canterbury.

- Riffkin, P. A., O'Leary, G., & Acuña, T. (2012). *The effects of plant growth regulators on winter and spring canola (Brassica napus L.) types in the High Rainfall Zone of south-eastern Australia*. Paper presented at the 16th Australian Agronomy Conference.
- Rodríguez-Rodríguez, M. F., Sánchez-García, A., Salas, J. J., Garcés, R., & Martínez-Force, E. (2013). Characterization of the morphological changes and fatty acid profile of developing *Camelina sativa* seeds. *Industrial Crops and Products*, 50, 673-679. doi: 10.1016/j.indcrop.2013.07.042
- RUSSO, R. (2013). *BIOCHEMICAL CHARACTERIZATION OF FLOUR FROM SEEDS OF CAMELINA SATIVA L.(CRANTZ) AFTER CHEMICAL EXTRACTION OF OIL*. Università degli Studi di Milano.
- Russo, R., & Reggiani, R. (2012). Antinutritive compounds in twelve *Camelina sativa* genotypes.
- Russo, V., Bruton, B., & Sams, C. (2010). Classification of temperature response in germination of Brassicas. *Industrial crops and products*, 31(1), 48-51.
- Sabaghnia, N., Dehghani, H., Alizadeh, B., & Mohghaddam, M. (2010). Interrelationships between seed yield and 20 related traits of 49 canola (*Brassica napus* L.) genotypes in non-stressed and water-stressed environments. *Spanish Journal of Agricultural Research*, 8(2), 356-370.
- Schillinger, W. F., Wysocki, D. J., Chastain, T. G., Guy, S. O., & Karow, R. S. (2012). Camelina: Planting date and method effects on stand establishment and seed yield. *Field Crops Research*, 130, 138-144.
- Schuster, A., & Friedt, W. (1998). Glucosinolate content and composition as parameters of quality of *Camelina* seed. *Industrial crops and products*, 7(2), 297-302.
- Séguin-Swartz, G., Nettleton, J. A., Sauder, C., Warwick, S. I., & Gugel, R. K. (2013). Hybridization between *Camelina sativa* (L.) Crantz (false flax) and North American *Camelina* species. *Plant Breeding*, 132(4), 390-396.

- Solis, A., Vidal, I., Paulino, L., Johnson, B. L., & Berti, M. T. (2013). Camelina seed yield response to nitrogen, sulfur, and phosphorus fertilizer in South Central Chile. *Industrial Crops and Products*, 44, 132-138.
- Soriano Jr, N. U., & Narani, A. (2012). Evaluation of biodiesel derived from Camelina sativa oil. *Journal of the American Oil Chemists' Society*, 89(5), 917-923.
- State, P. (2014). Growing Canola and Camelina. *Penn State Extension*. Retrieved May 01, 2014
- Tulloch, J. (2009). A look at the top biofuel crops. Retrieved June 17, 2014
- Urbaniak, S., Caldwell, C., Zheljazkov, V., Lada, R., & Luan, L. (2008). The effect of seeding rate, seeding date and seeder type on the performance of Camelina sativa L. in the Maritime Provinces of Canada. *Canadian Journal of Plant Science*, 88(3), 501-508.
- US Department of Energy. (2013). ASTM Biodiesel Specifications. *Energy Efficiency & Renewable Energy*. Retrieved October 08, 2013
- US Department of Energy. (2014). Biodiesel. *Alternative Fuels Data Centre*.
- Velasco, L., Fernández-Martínez, J., Garcia-Ruiz, R., & Dominguez, J. (2002). Genetic and environmental variation for tocopherol content and composition in sunflower commercial hybrids. *The Journal of Agricultural Science*, 139(04), 425-429.
- Vollmann, J., Moritz, T., Kargl, C., Baumgartner, S., & Wagentristl, H. (2007). Agronomic evaluation of camelina genotypes selected for seed quality characteristics. *Industrial Crops and Products*, 26(3), 270-277.
- Wu, X., & Leung, D. Y. (2011). Optimization of biodiesel production from camelina oil using orthogonal experiment. *Applied Energy*, 88(11), 3615-3624.
- Wysocki, D., & Sirovatka, N. (2008). Camelina, a Potential Oilseed Crop for Semiarid Oregon. *2008 Dryland Agricultural Research Annual Report*, 86.

- Zakharchenko, N., Kalyaeva, M., & Buryanov, Y. I. (2013). Expression of cecropin P1 gene increases resistance of *Camelina sativa* (L.) plants to microbial phytopathogenes. *Russian Journal of Genetics*, 49(5), 523-529.
- Zaleckas, E., Makarevičienė, V., & Sendžikienė, E. (2012). Possibilities of using *Camelina sativa* oil for producing biodiesel fuel. *Transport*, 27(1), 60-66.
- Zohary, D., Hopf, M., & Weiss, E. (2012). *Domestication of Plants in the Old World: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean Basin*: Oxford University Press.
- Zubr, J. (1988). Biomass for energy from field crops. *International journal of solar energy*, 6(1), 33-50.
- Zubr, J. (1997). Oil-seed crop: *Camelina sativa*. *Industrial crops and products*, 6(2), 113-119.
- Zubr, J. (2003). Qualitative variation of *Camelina sativa* seed from different locations. *Industrial Crops and Products*, 17(3), 161-169.
- Zubr, J., & Matthäus, B. (2002). Effects of growth conditions on fatty acids and tocopherols in *Camelina sativa* oil. *Industrial crops and products*, 15(2), 155-162.

