Secrets of the Seeds

– Exploring the relationship between seed morphology and seed quality in *Lepidium campestre*, a novel oil crop for Northern Sweden

Ludvig Pettersson Landgren

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Swedish University of Agricultural Sciences, SLU
Department of Biosystems and Technology
Horticultural Management: Gardening and Horticultural Production – Bachelor's programme
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Abstract

This study set out to explore relationships between seed morphology and qualitative traits in field cress, *Lepidium campestre,* with the goal of assisting the breeding process of this crop under domestication.

A collection of seeds of *L. campestre* as well as related species was analysed for weight and size using a MARViN seed analyser. Seed colour was examined through the development of a colour gradient-based method. These traits were then compared to previous agronomic and seed quality data gathered on the seeds of the collection. The data previously collected included flowering time, seed weight per plant, oil content and fatty acid composition, as well as the level of glucosinolates, an anti-nutrient, in the seeds. A series of correlation analyses were made to show correlations between them.

The analyses revealed little to no correlation between seed colour and other seed qualities, suggesting that seed colour is not an indicator of seed quality, at least in the traits that were examined in this study. There was a correlation between seed size and oil content, showing that larger seeds contain more oil. There was also a positive correlation between glucosinolate content and oleic acid content, suggesting that the two are linked. Another correlation was found between flowering time and seed weight, showing that there was an optimal time interval for the plants to flower for the seeds to be fully developed: between 115-120 days.

Keywords: Lepidium campestre, field cress, oil crop, plant breeding, domestication, seed morphology, seed colour, seed analysis, Northern Sweden, glucosinolate

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1. Introduction

1.1. Background

There is a great need of sustainable sources of biofuels as an alternative to fossil fuels. This is true all around the world, and Sweden is no exception. One such source is vegetable oil from oil crops, of which in Sweden rapeseed, turnip rape, and flax are cultivated. However, the cultivation of these is almost entirely confined to southern Sweden, as they are not suitable to cultivate in the colder climates and shorter growth periods of northern Sweden. This means that a lot of arable land remains either sown with ley, or remain fallow in northern Sweden, and so a lot of economic potential goes unfulfilled (Hammenhag et al. 2020).

This is not a problem that is exclusive to Sweden; in fact, it is true for many countries in the northern part of the temperate region. Therefore, there is a need for novel oil crops that can thrive in cold climates and a shorter growing period while producing high amounts of quality oil. One of the prime candidates to be domesticated as a novel oilseed crop for this region and purpose is *Lepidium campestre*, or field cress (Eriksson 2019).

1.2. The plant

Lepidium campestre is a plant in the mustard family, Brassicaceae. It is originally native to Europe, where it grows in most kinds of soil, on disturbed land, waste places, or as a weed growing alongside food crops. The plant is edible, as the young leaves can be eaten as protein-rich raw greens in salads. The seeds and fruits have a peppery taste and can be used as a spice (Plants for a Future n.d.).

In Sweden today, field cress is mostly seen as an unimportant plant, as well as being an invasive weed in parts of North America where it is subject for eradication wherever it appears. It has a short growth cycle, is hardy in southern and northern Swedish climates, and is hard to eradicate (Mistra Biotech 2020).

The wild field cress differs from its close relatives, rapeseed, turnip rape, and flax by handling cold climates well. Turnip rape is generally grown further North than rapeseed and flax, but field cress is still superior in this regard. The oil from field cress could be used as biofuels or in foods, and the seed cake (left-over product from oil extraction) as protein-rich animal feed. There is even the possibility that it could be grown as a vegetable for people. These qualities make it a good candidate for use as a future sustainable biannual oil and feed crop. It could be grown by farmers in northern Sweden, as well as in other regions of the world with similar climate, such as North America, and northern Russia. In the future, field cress could contribute towards making Sweden more self-sufficient, as well as provide a good source of income for farmers in Sweden and beyond. (Mistra Biotech 2020).

The idea is to use field cress as a cover crop, grown together with spring wheat or spring barley. The two crops are sown together and wheat/spring barley is harvested in the first year, while the field cress is left to grow and flower during the following year, when it is then harvested. Being biannual, the field cress act as a ground cover, retaining nutrients in the soil, reducing erosion, and preventing weeds from taking over. In this way, field cress can be grown where there are few other options, increasing the use the farmer can get out of the field. Field cress would then replace the less productive ley/grassland for a more varied, and thus more efficient, crop rotation (Mistra Biotech 2020).

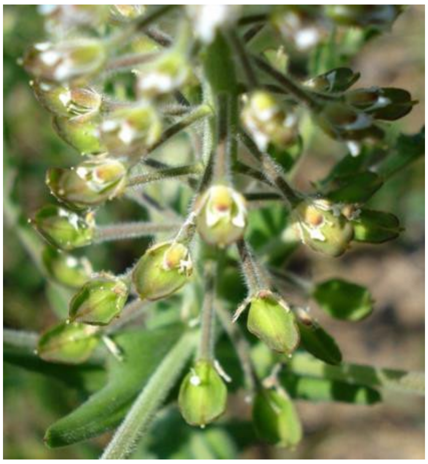


Figure 1. Photo of L. Campestre in the wild (Fornax 2008).

In its current state, however, field cress contains too high levels of the anti-nutrient glucosinolate for its seed oil to be considered as a viable food source and the seed cake as feed. In addition, the oil content is relatively low and the oil composition is not optimal for the oil to be consumed as food. Thus, there is a need for further improvement, to increase oil and seed yield, and to improve the quality and production of oil, while decreasing the levels of glucosinolates (Mistra Biotech 2020)

1.3. The domestication project

The idea of domesticating oil seed crops is not a recent one. Since before the 1950s, researchers have been planning and pondering new potential crops for sustainable oil production. Nonetheless, new wild crops being domesticated is a rare thing, and yet with the introduction of new technologies for plant breeding, such as hybridisation, genomic selection, and genetic engineering, the process of domestication is now faster, easier, and cheaper than ever before (National Science Foundation n.d.).

At the Swedish University of Agricultural Sciences (SLU), a project has been running for nearly 30 years with the goals of domesticating field cress into a viable crop. This would be the first time that a native wild plant has been domesticated into an oil and food crop in Sweden (Gustafsson et al. 2018).

The project was started by the late Professor Arnulf Merker in the early 1990s. Research on field cress was initiated and increased in intensity as of 2005 and is still ongoing today. The project was initially sponsored by SLU, The Swedish Foundation for Agriculture Research (SLF), and Svensk Raps. After Merker passed away in 2010, the project found funding from SLU, Mistra Biotech, Formas, as well as additional minor sources (Mistra Biotech 2020).

By the time of writing, the project has made considerable advances, not least of all is the identification of more than 30 genes that govern different traits in field cress, through comparative genomics using related plants in the Lepidium genus and the model organism *Arabidopsis thaliana* (a relatively close relative of field cress). However, there are still a number of undesirable traits that make field cress not ready for commercialisation, and it is these traits that are currently being targeted for improvement (Gustafsson et al. 2018).

Figure 2. Field cress plant in selection-based field trials, Alnarp Sweden 2018 (Cecilia.gustafsson1981 2018*).*

1.4. Glucosinolates

Glucosinolates are secondary metabolites that appear in many different plants, and especially in the Brassicaceae family, field cress amongst them (Wu et al. 2021). They act as deterrents against pests and herbivores and their synthesis are generally triggered upon contact. Glucosinolates can be toxic for humans in high concentrations, and in wild field cress, the amounts are high enough to make field cress seed cakes non-suitable for eating (Mistra Biotech 2020). The current levels for glucosinolates in rapeseed seed cake are around 30 µmol/g (European Food Safety Authority 2008) while field cress has been shown to have levels around 300 µmol/g (Isoz 2018). One major goal of the domestication project is therefore to decrease the amounts of glucosinolates in the seeds.

1.5. The aim of this study

A collection of around 300 accessions of *Lepidium campestre* has previously been genotyped using SeqSNP and analysed for plant seed yield, flowering time, glucosinolate levels, oil content, and fatty acid composition. The fatty acids analysed are oleic acid (18:1) and erucic acid (22:1), which are the most important for the use of field cress oil as a food oil, and the seed cake as feed.

In this project, seeds of each accession of field cress were analysed and weighed using a MARViN seed analyser. In addition, a method for determining seed colour was developed and seed colour for the collection will thereafter be determined. Finally, previous data on plant seed yield, flowering time, glucosinolate levels, oil content, and fatty acid composition was compiled and compared to the data that has been collected within this project. For this purpose, correlation analyses were performed in an attempt to find associations between seed colour, seed morphology, phenological data, and seed quality data. Understanding the correlations between different morphological and phenological data could greatly aid the domestication and breeding processes of field cress.

2. Materials and Method

2.1. Plant material

A collection of 300 accessions of *L. campestre*, the close relative *L. heterophyllum*, and hybrids thereof were included in the study. The accessions were represented by four seed samples each: A1, A2, B1, and B2. A1 and A2 were derived from plants grown in a greenhouse, while B1 and B2 were derived from plants grown outside in a net yard at SLU Alnarp during 2020. Not all accessions were complete (not represented by the four samples), as some samples had been used for previous studies. There was also a few of the accessions that contained too few seeds – less than 50 – to make a proper analysis. These were therefore not included in the analyses. The aim was to use one seed sample per accession, with a priority on the B2 versions, as the idea is that the final domesticated plant will be grown outside in the field. Where these were missing, A1, then A2, and finally B1 were used instead. In total 319 seed samples were used in the study, of which 222 were from group B and 97 from group A. Where necessary, the samples were filtered through a thin-meshed sieve to remove smaller pieces of waste plant matter that might otherwise interfere with the measurements.

MARViN ProLine 1 seed analyser with scale.

2.2. Seed phenotyping

The seeds of the 319 Lepidium accessions were measured for weight (TGW – *Thousand Grain Weight*), size (area), width, and length using a MARViN ProLine 1 seed analyser (referred to in later text as simply *Marvin*), and a scale. After collected, the data was stored on an Excel sheet.

A sample from each seed bag containing roughly 100-300 seeds was then photographed with an iPhone camera against a white background. The seeds were then manually put into five different colour categories: 1) Light brown, 2) Reddish brown/red, 3) Reddish brown and dark brown mixed (some reddish brown, some dark brown), 4) Red/dark brown, and 5) Dark brown/black. Seeds that appeared to have a disease or that had been dried out were not included in the colour determination analysis.

2.3. Agronomical and seed quality data from previous analyses

The 319 accessions had previously been analysed for various agronomically qualities/traits, such as days to flowering and seed yield per plant, as well as seed components such as oil content, fatty acid composition, and glucosinolate levels.

Days to flowering was measured as the number of days from sowing until the first white petal was observed on each group, A and B. Seed yield is the final weight of all seeds harvested from one plant. Oil content (total fatty acid content in the seeds) and fatty acid composition were measured through a process where seed lipids were extracted using a chloroform-based method and an aliquot of the lipid extract was then analysed with a Gas Chromatograph (GC) (Ivarson et al. 2017). Glucosinolates were extracted with a methanol-based method and purified using a Sephadex A-25 column. Afterwards, the glucosinolates were separated on a reverse-phase High Pressure Liquid Chromatography (HPLC) column and detected with a UV-Vis Absorption detector (Isoz 2018).

There was one part of the seed collection that was not analysed for glucosinolates, and so these were not used in correlation analyses on glucosinolate content.

2.4. Pairwise correlation analyses

The Marvin data was compiled in an Excel sheet together with the previous data.
The correlation analyses were performed with the software Minitab. The data in the pairwise correlation analyses between different traits included the following:

- Seed size (area) and seed weight (TGW)
- Seed size (area) and oil content
- Seed colour and glucosinolate content
- Seed colour and oil content
- Seed colour and oleic acid (18:1) content
- Seed colour and erucic acid (22:1) content
- Seed colour and seed weight (TGW: *Thousand Grain Weight*)
- Seed colour and seed yield per plant
- Glucosinolate content and oil content
- Glucosinolate content and oleic acid content (18:1)
- Glucosinolate content and erucic acid content (22:1)
- Days to flowering and oil content
- Days to flowering and glucosinolate content
- Days to flowering and seed yield per plant
- Oil content and oleic acid (18:1)
- Oil content and erucic acid (22:1)

Both the Pearson correlation method and Spearman correlation methods were used. The Spearman method was used for the categorical data: days to flowering and seed colour, while the Pearson method was used for the continuous data: oil and fatty acid content, seed weight and size, and glucosinolate levels.

3. Results

3.1. Seed colour

The colours of the seeds were determined through the development of a colour gradient scale. All photographs taken of the seeds were examined visually , and five colour groups were then selected that were distinct enough to easily tell apart. The seed samples were each put into one of these five categories through visual inspection of the photos. The categories of the colour gradient were:

1. Light brown
2. Reddish brown/red
3. Reddish brown and dark brown mixed (some reddish brown, some dark brown)
4. Red/dark brown
5. Dark brown/black

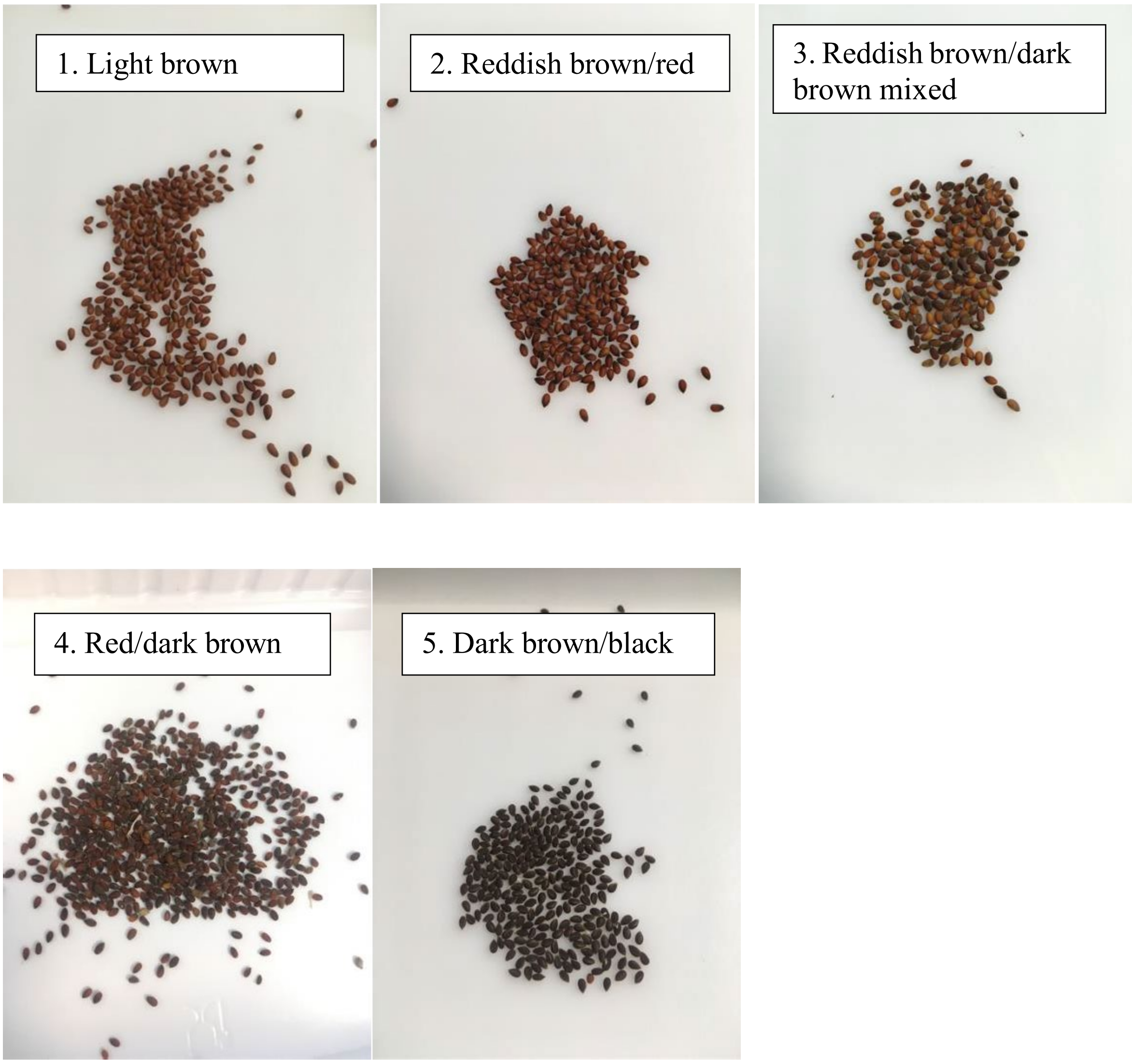
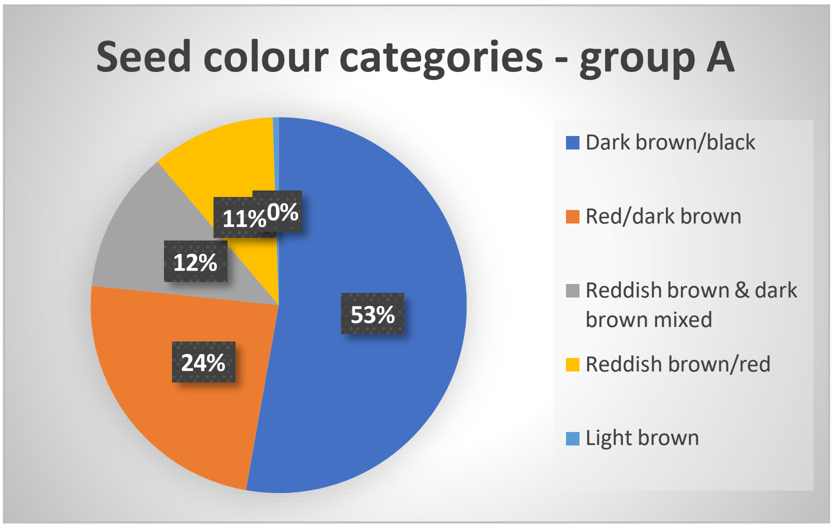


Figure 3: Examples of the five categories of the colour gradient scale.

The examination of seed colour showed that the colour was more uniform in group A(the greenhouse-grown), and showed an overall darker colour, with a large majority category 5 (Figure 4A) as compared to group B (outdoor grown). In the group B, the colours of seeds varied considerably more (Figure 4B).

4A



4B

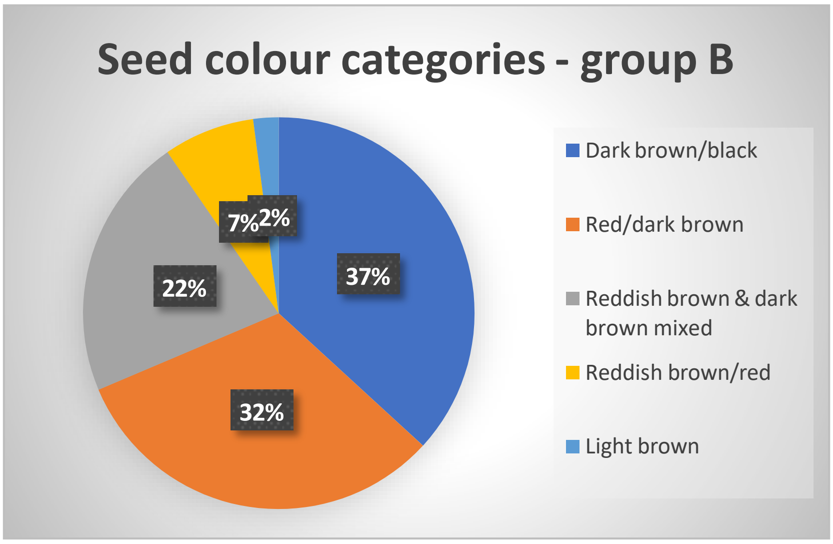


Figure 4. Percentages of seed colour categories of group A (greenhouse-grown), out of 97 samples (A) and of group B (outdoor-grown), out of 222 samples (B).

3.2. Seed size and weight

The data on seed morphology was collected by Marvin, analysed in Excel, and then plotted in a series of graphs. The analysis shows that there was considerable variation in the weight of the seeds (TGW) and the area of the seeds (Figure 5 and 6). The TGW varied between 0.48 – 3.33 g while the seed area ranged between 1.1 to 3 mm. Thus, there was a larger variation among accessions in seed weight with a 9-fold difference as compared to seed size that only showed a 3-fold difference.

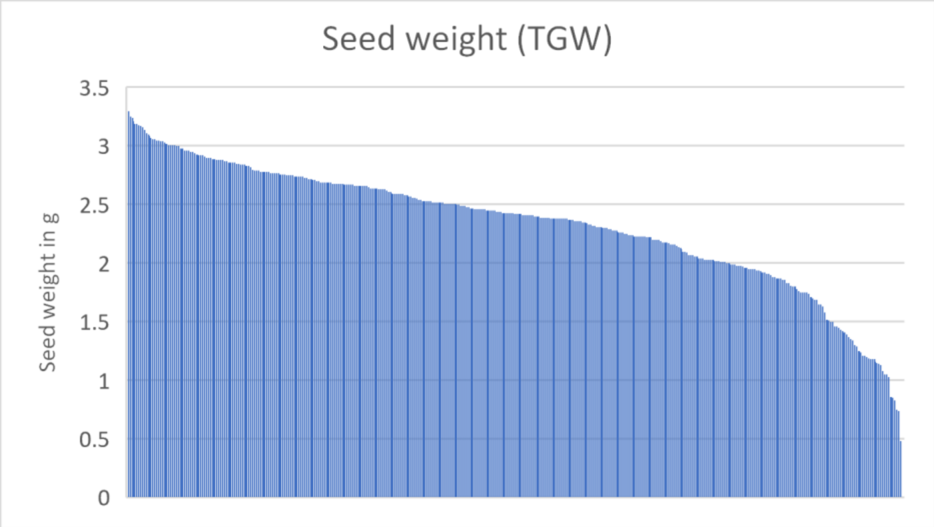


Figure 5. Seed weight (g) measured as TGW, amongst the seed samples of the collection. Each bar in the graph is represented by one seed sample (accession). The results show a large variation in seed size amongst accessions.

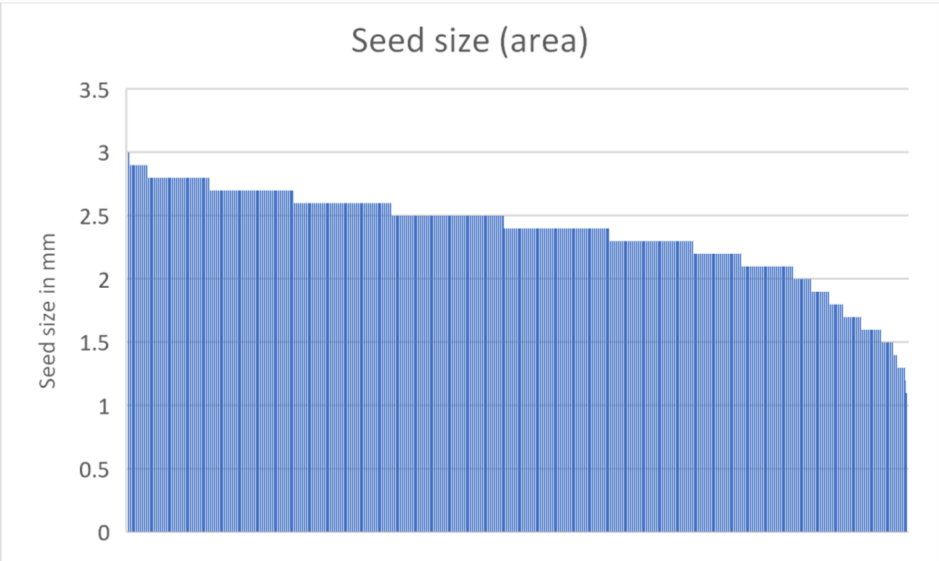


Figure 6. Seed size (mm) measured as area amongst the seed samples of the collection. Each bar in the graph is represented by one seed sample (accession).

3.3. Days to flowering

The days from sowing to flowering varied between 103-127 days (Figure 7).

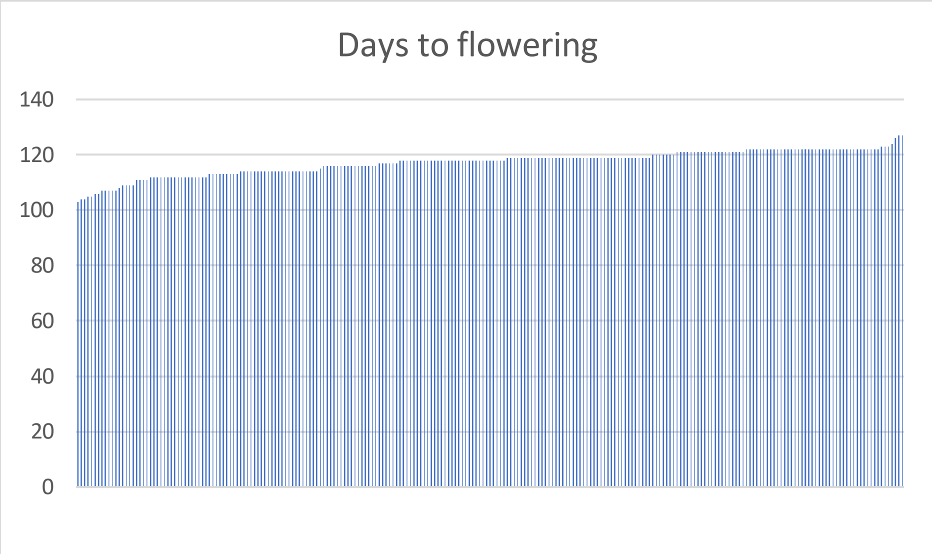


Figure 7. Days from sowing to flowering amongst the plants of the seed collection. Each bar in the graph is represented by one plant.

3.4. Oil content

There was a large variation in the oil content of the samples: between 2.5-20% by seed weight (Figure 8).

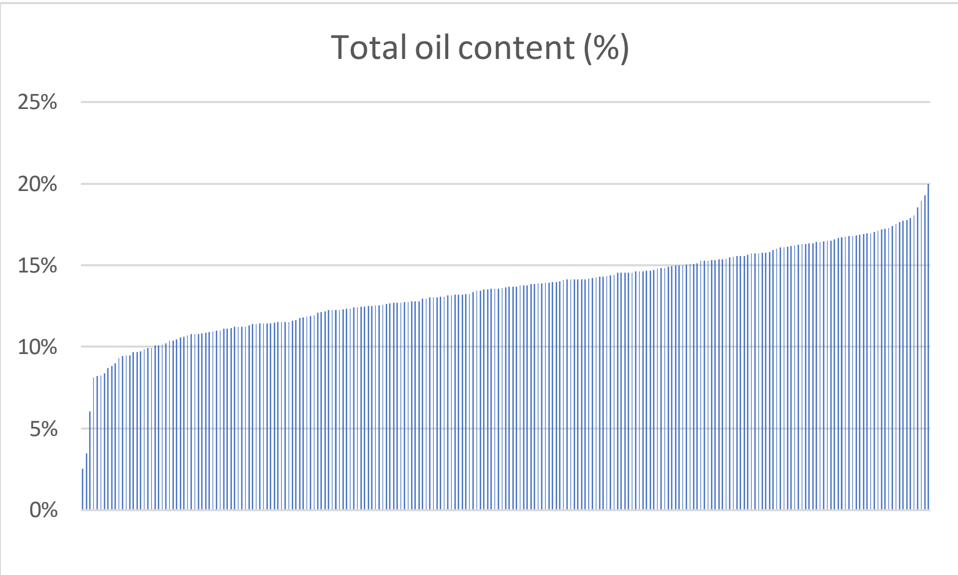


Figure 8. Oil content (% of seed weight) amongst the seed samples of the collection. Oil content represents fatty acids in total lipids. Each bar in the graph is represented by one seed sample (accession).

3.5. Fatty acid composition

The oleic acid content in the seeds varied considerably among accessions, between 5.2-18.8% (Figure 9). The erucic acid varied between 13.2-32.9% (Figure 10).

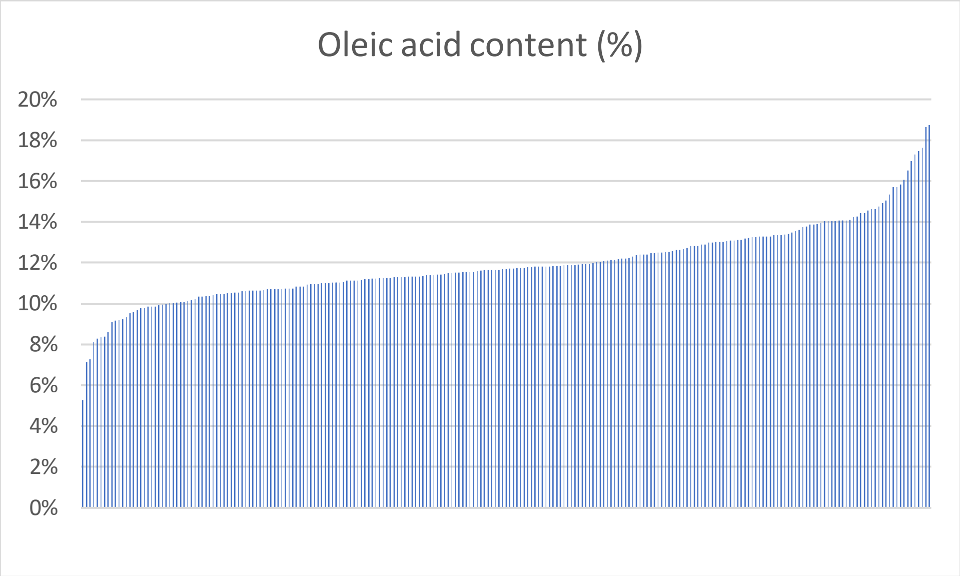


Figure 9. Oleic acid (18:1) content in % of total fatty acids amongst the seed samples of the collection. Each bar in the graph is represented by one seed sample (accession).

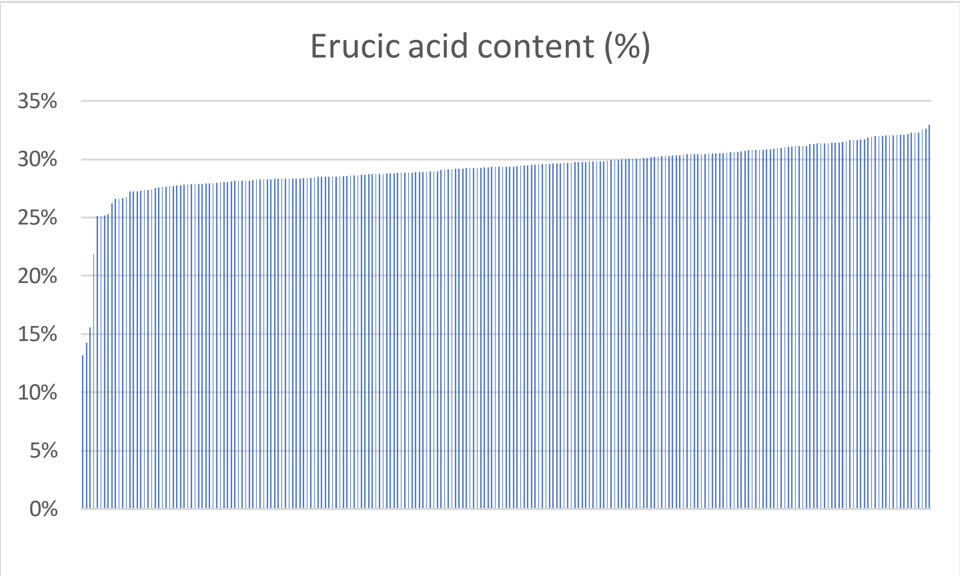


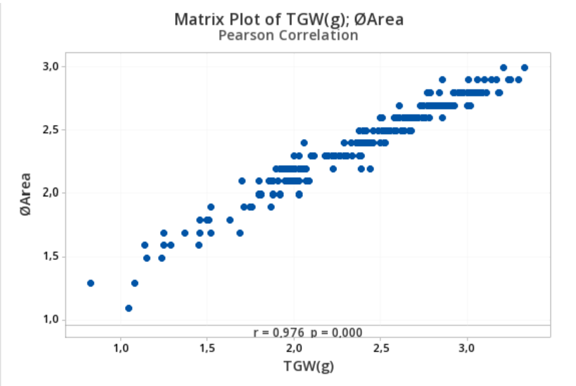
Figure 10. Variations in erucic acid (22:1) content in % out of total fatty acids amongst the seed samples of the collection. Each bar in the graph is represented by one seed sample (accession).

3.6. Pairwise correlation analyses

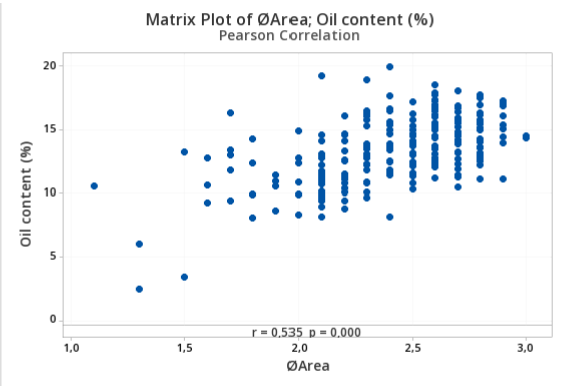
A series of pair-wise correlation analyses between traits were made in Minitab to find possible connections between different morphological and phenotypical seed qualities. Correlations described here are regarded significant when $P<0.05$. The analysis showed a significant positive correlation between seed weight and seed size ($r=0.976$, Figure 11A). As shown above, however, there was a bigger difference in seed weight than size (Figure 5 and

6). Additionally, there is a significant positive correlation between seed size and oil content, meaning that the larger the seeds, the higher the oil content (r= 0.535, Figure 11B).

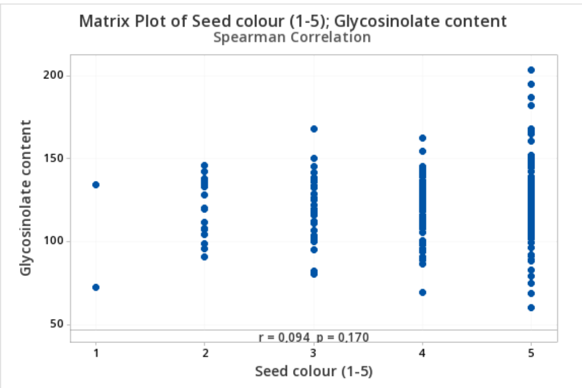
There was a low correlation between seed colour and morphological- or seed qualities (r-values between -0.025 & 0.151, Figure 11C-H). A weak, but significant correlation was seen between seed colour and oleic acid, however (R=0.151, Figure 11E). Further, there was no significant correlation between oil content and glucosinolate content (Figure 7I). However, there was a weak correlation between glucosinolate content and oleic acid in the seeds (r= 0.183, Figure 11J). There were no significant correlations between glucosinolate content and erucic acid content (Figure 11K) or between days to flowering and oil content (Figure 11L). There was an indication of a weak positive correlation between days to flowering and glucosinolate content in the seeds, but this did not pass the significance level (Figure 11M). There was a significant positive correlation between days to flowering and seed weight: up to a certain point, the faster the plant flowers, the heavier the seeds; the optimal time to flowering is shown to be roughly between 115 to 120 days (R= 0.164, Figure 11N). There was a weak negative correlation between oil content and oleic acid content (r=-0.207, Figure 11O). There was, however, a weak positive correlation between oil content and erucic acid (r=0.288, Figure 11P).



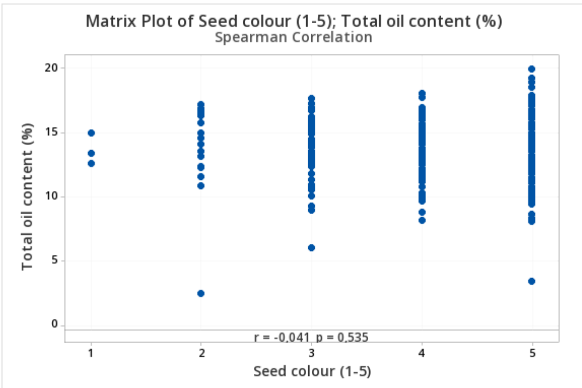
A.



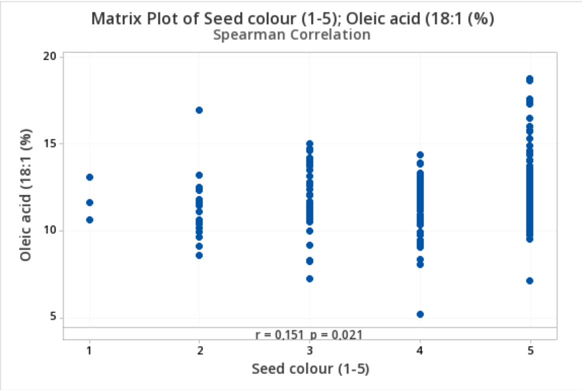
B.



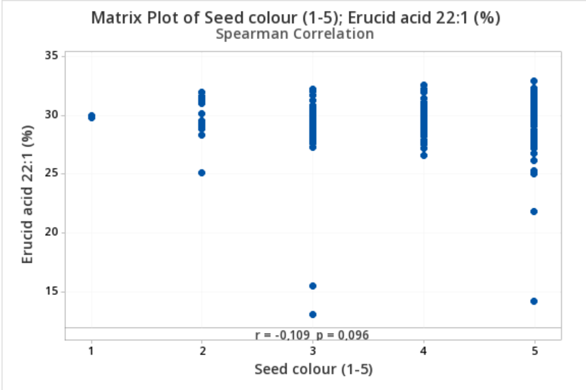
C.



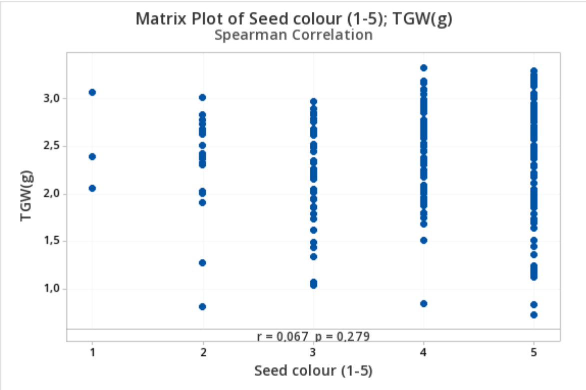
D.


Matrix Plot of Seed colour (1-5); Oleic acid (18:1 (%)
Spearman Correlation
Oleic acid (18:1 (%)
r = 0,151 p = 0,021
Seed colour (1-5)

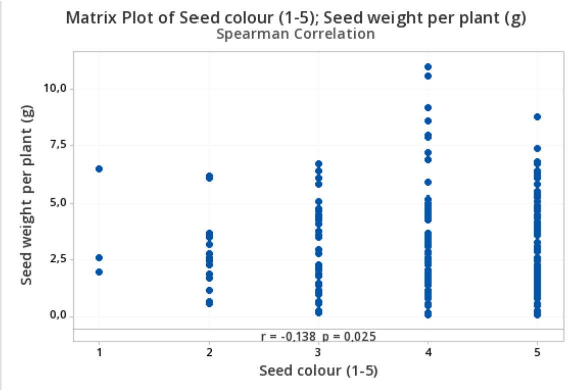
E.


Matrix Plot of Seed colour (1-5); Erucid acid 22:1 (%)
Spearman Correlation
Erucid acid 22:1 (%)
r = -0,109 p = 0,096
Seed colour (1-5)

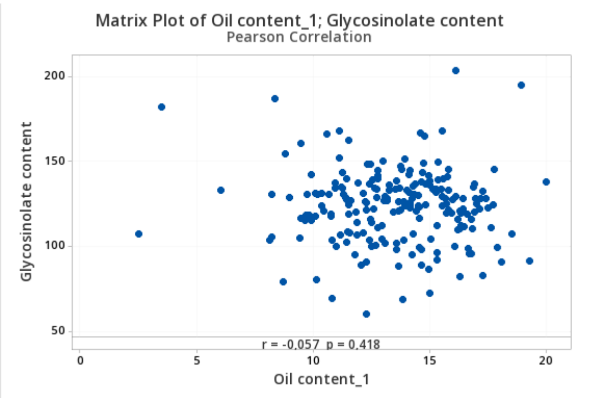
F.


Matrix Plot of Seed colour (1-5); TGW(g)
Spearman Correlation
TGW(g)
r = 0,067 p = 0,279
Seed colour (1-5)

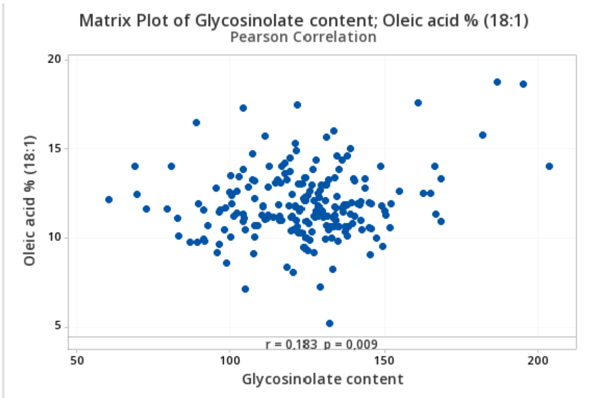
G.


Matrix Plot of Seed colour (1-5); Seed weight per plant (g)
Spearman Correlation
Seed weight per plant (g)
r = -0,138 p = 0,025
Seed colour (1-5)

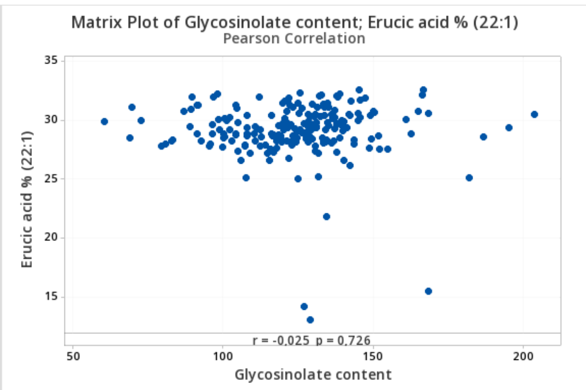
H.


Matrix Plot of Oil content_1; Glycosinolate content
Pearson Correlation
Glycosinolate content
r = -0,057 p = 0,418
Oil content_1

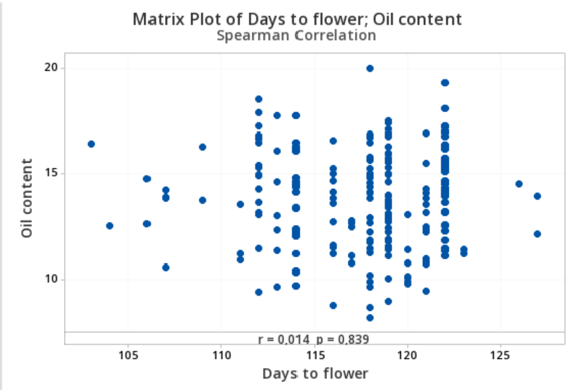
I.


Matrix Plot of Glycosinolate content; Oleic acid % (18:1)
Pearson Correlation
Oleic acid % (18:1)
r = 0,183 p = 0,009
Glycosinolate content

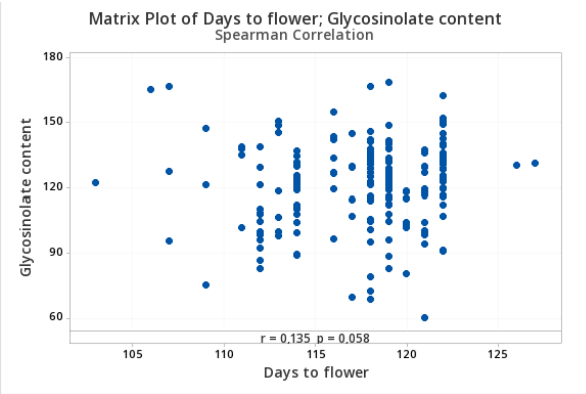
J.

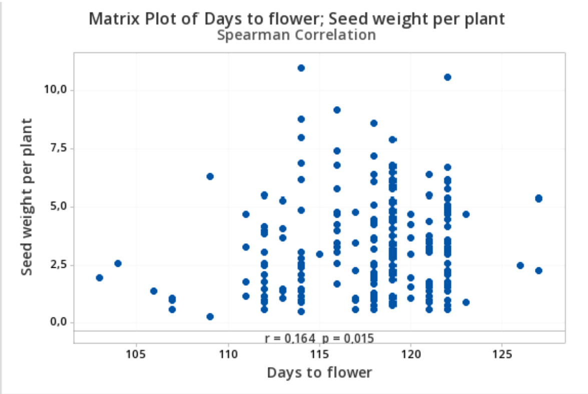

Matrix Plot of Glycosinolate content; Erucic acid % (22:1)
Pearson Correlation
Erucic acid % (22:1)
r = -0,025 p = 0,726
Glycosinolate content

K.


Matrix Plot of Days to flower; Oil content
Spearman Correlation
Oil content
r = 0,014 p = 0,839
Days to flower

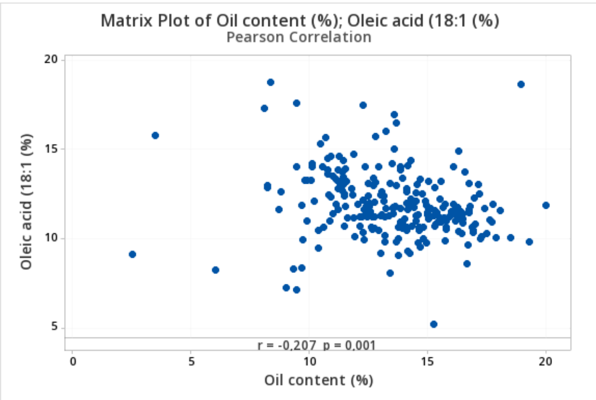
L.

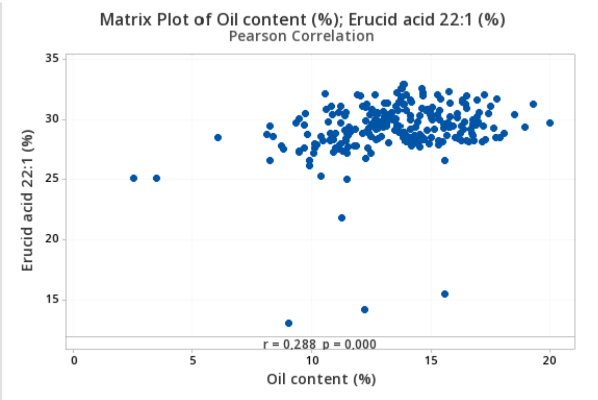




M.

N.





O.

P.

Figure 11. Pair-wise correlation analyses between traits by either Pearson or Spearman methods. r- and p-values are included in the graphs.

A. Seed size (area) and seed weight (TGW)
B. Seed size (area) and oil content
C. Seed colour and glucosinolate content
D. Seed colour and oil content
E. Seed colour and oleic acid (18:1) content
F. Seed colour and erucic acid (22:1) content
G. Seed colour and seed weight (TGW: Thousand Grain Weight)
H. Seed colour and seed yield per plant
I. Glucosinolate content and oil content
J. Glucosinolate content and oleic acid (18:1) content
K. Glucosinolate content and erucic acid (22:1) content
L. Days to flowering and oil content
M. Days to flowering and glucosinolate content
N. Days to flowering and seed yield per plant
O. Oil content and oleic acid (18:1) content
P. Oil content and erucic acid (22:1) content

4. Discussion

4.1. Seed colour

This project aimed to identify possible correlations between seed morphological and qualitative traits in a collection of seeds from field cress, in order to assist the domestication process of the plant. Seed colour was determined by hand using a colour gradient scale, seed weight and size were measured by Marvin, and correlation analyses were made in Minitab.

The colour determination process was at times not simple, but that is to be expected when doing these kinds of analyses by hand. There were samples with much colour variation amongst the seeds, which is why category 3 (Reddish brown and dark brown mixed) was included. The results from the seed colour analyses revealed that the ratios of different seed colour categories were quite different between group A and B, with group A seeds being generally darker in colour than group B, where the colours were more varied. This was not surprising, as there would be more factors influencing the plants grown outdoors.

There are many factors influencing seed morphology and colour, from genetic variability through gene expression, to environmental factors both biotic and abiotic, and these are harder to control in the field. A greenhouse environment, by comparison, is easier to control and regulate, and therefore the plants and their seeds should be more uniform (Mitchell et al. 2017). Future studies could examine this by including both an indoor and an outdoor version of each seed sample, to better examine the differences between them.

One of the many factors that can influence seed colour is maturation level. In some cases, the plants might not have been harvested at the optimal time of maturation, in part because the optimal harvest time of a given plant is not always known, and in part because of the logistical difficulties of harvesting 1200 individual plants at the optimal time. Some plants also have so-called indeterminant flowering habit, meaning that they flower continuously instead of after a certain time, and this could make it harder to harvest the entire crop collection at one time. This means that some of the seed colour variation presented in this study could be down to sub-optimal harvest times.

The measuring of seed colour could also have been made with a spectrophotometer, and/or with the help of a digital imaging system, instead of by hand as was done in this study. This would most likely have led to a greater exactness and detail compared to the approach used in this study. The human factor would have been less involved in this case.

On the other hand, there are also advantages to the approach used for this study. In the case of the seed measurements done with Marvin, there was sometimes the need to correct the program when it counted non-seeds (referred to by the program as *black stocking*) as real seeds. There is every possibility that the same problem could arise should a software program – or even an artificial intelligence, as seems to be more and more common nowadays – be used to measure colour hues. Until the technology improves further, colour measurement by hand is still a viable option, at least for the number of samples used in this study. Had the collection been larger, there would be need for a different approach.

Increasing the number of seed colour categories might have led to more exact data, but it would likely not have made much difference for the results.

4.2. Seed size and weight

The observed seed weight difference between accessions was large and could be the result of many different factors. A majority of the analysed accessions came from plants grown in and outdoor environment, where conditions are harder to control than in a greenhouse. Weather variation, genetic factors, as well as differences in access to water and nutrients are just a few factors to consider. A high degree of variation is therefore to be expected.

The size (area) of the seeds, however, exhibited less variation between accessions than the weight, which was a bit unexpected. This suggests that even though the seeds might have a larger area, this does not necessarily translate into more biomass (total seed content). It should be noted that the seed area measured by Marvin is the two-dimensional area when the seed lies on a flat surface (and not the full 'spherical area'). Therefore, the seeds could, for example, be flat, which Marvin will interpret as larger, while still having a relatively low seed weight.

Several of the seed bags in the collection contained waste plant matter that was included during the harvest process, such as empty seed pods and leaf litter. This plant matter could interfere with Marvin's scans and influence seed counting, size, and weight. As Marvin can be somewhat erratic in what it counts as seeds or not, the samples that contained lots of waste plant matter might have included some non-seeds not counted as black stocking, which affects the data. Efforts were made, however, to minimise the amount of such interference, and so the actual margin of error should be insignificant.

4.3. Correlation analyses

As expected, there was a strong correlation between seed weight and seed size. However, there was a larger variation in seed weight than size. There was also a strong correlation between seed size and oil content, meaning that the larger the seeds, the higher the percentage of oil. This could be beneficial, as one of the goals of the domestication project is to produce higher yields and larger seeds. The fact that the oil content increases along with the size is therefore promising results for further breeding. However, when it comes to some plant species, larger seeds in some cases also means smaller harvests (fewer total seeds per plant) (Sripathy & Groot 2023). Therefore, more research will have to be made into this.

When it comes to the correlations between seed colour to other traits (figures 11C-H), there was very little sign of correlations in any of the analyses made. This is unfortunate, as having a clear connection between the colour of the seeds and traits such as oil or glucosinolate content would have been very beneficial to the breeding- and domestication processes of field cress. By tying a certain quality to a certain seed colour, efforts could be made relatively simple to select those seeds for further trials. Despite this fact, the result that there was little to no correlation does allow this factor to be discounted in future tests, at least for the here studied seed quality traits.

There was a positive correlation between glucosinolate content and oleic acid content, and recent research seems to agree. A master's thesis from 2023, which has looked at the same data as in this study while also including genomic data, has revealed polymorphisms that show that alleles linked to higher oil content often also links to increased levels of glucosinolates (Lodenius 2023). This is important, as one of the main goals of the domestication project of field cress is to decrease the amount of glucosinolates, while increasing the amount and quality of the oil. This means that a strategy of separating the two traits needs to be found and further research will have to be done on this.

A weak correlation between days to flowering and glucosinolate content in the seeds was shown and a correlation between days to flowering and seed weight was also observed. Up to a certain point, the earlier the plant flowers, the heavier the seeds. This is likely because the earlier a plant flowers, the sooner the seeds are produced, giving them more time to mature and grow before harvest. The data in this study also suggests, however, that if the plant flowers before a certain point – too soon – the seeds are much smaller and lighter. Recent research suggests that this is because the plant does not have enough biomass by that point to allow for optimal maturation of the seeds, and that harvesting seeds too early often leads to poor quality (Sripathy & Groot 2023), thus confirming the results shown in this study. This would at least in part explain the results seen in figure 11M as well. The results showed that there was a rough optimal time for the plants to flower, if the goal is to produce as large seeds, with as much oil, as possible: between 115 and 120 days (Figure 7). There was a certain degree of variation in the days to flowering, between 103-127, which then would have affected the size and weight of the seeds. In this study, 70 out of the 319 accessions fell into the 115-120 days category (Figure 7).

The weak correlation between oil content and erucic acid (Figure 11P) is notable. Too much erucic acid is undesirable in *L. campestre*, as it contributes to making the oil and seed cake unsuitable for animal and human consumption (Sandgrind et al. 2023). The fact that the correlation is weak, however, means that more research will have to be done to draw final conclusions.

5. Conclusion

This study set out to explore relationships between seed morphology and qualitative traits in field cress, *Lepidium campestre*. Based on analyses of a large seed collection at SLU Alnarp, several interesting connections were discovered. The analyses made focused on the correlations between seed colour, weight, and size, and oil content and composition, flowering time, and glucosinolate content.

First of all, the results show that there are clear differences in colours of seeds from plants grown in a greenhouse versus in an outdoors environment. The seeds coming from greenhouse-grown plants were generally darker and more uniform amongst accessions, as compared to the seeds from outdoor-grown plants which were more varied overall. No clear correlations between seed colour and morphological or phenotypical traits were found, however, proving that seed colour is not a useful indicator of seed quality for the traits included in this study.

Secondly, the results showed a weak but significant correlation between glucosinolate content and oleic acid content, suggesting the two are somewhat linked. This will require further research, as the goal of the domestication project is to lower the amount of glucosinolates, while increasing the amount of oil.

Thirdly, a correlation was found between days to flowering and seed weight, but only to a certain point. If the plant flowers too late, the seeds won’t have time to mature before harvest, and if they flower too early, the plant lacks the biomass to allow them to mature properly, leading to smaller, lighter seeds. The optimal flowering time to achieve a high seed weight was then between 115-120 days.

The conclusions from this study have shown several correlations between seed morphological traits and seed quality, and this will assist in the domestication process of field cress, while contributing to future efforts in optimising the plant for commercial use as a novel oil crop for Northern Sweden and beyond.

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Picture 1: Fornax (2008). *Lepidium campestre*. [photograph]. https://en.wikipedia.org/wiki/Lepidium_campestre#/media/File:Lepidium_campestre2_W.jpg (CC BY-SA 3.0) [2023-05-17]

Picture 2: Cecilia.gustafsson1981 (2018) *Field cress plant in selection based field trials*. [photograph]. https://en.wikipedia.org/wiki/Lepidium_campestre#/media/File:20180625_Alnarp4.jpg (CC BY-SA 4.0) [2023-04-02]

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