The potential for landraces to be used for climate adaption in Swedish agriculture

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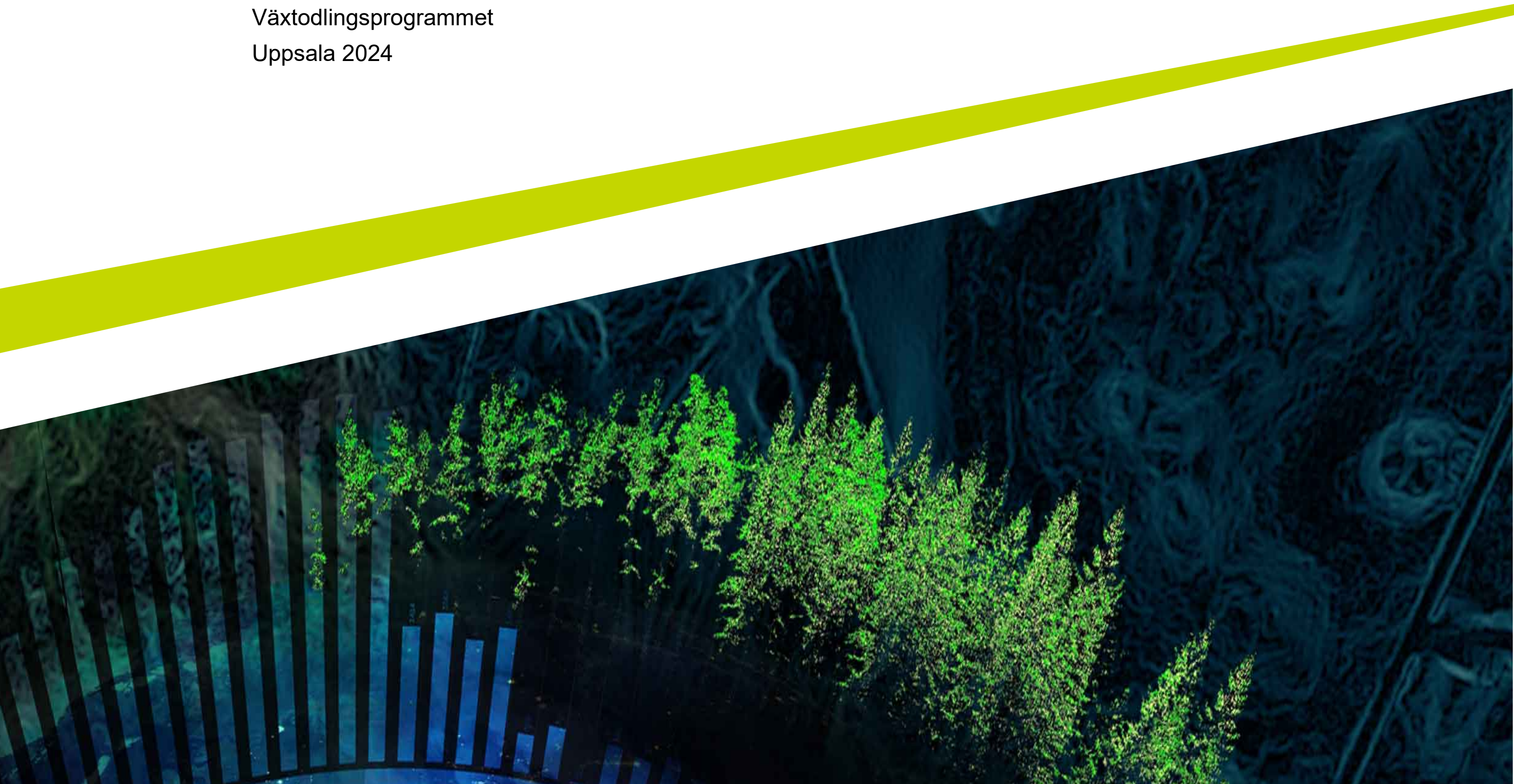

The potential for landraces to be used for climate adaption in Swedish agriculture

Potentialen för lantsorter att användas för klimatanpassning av det svenska jordbruket

Linnea Berggren Sjögård

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Abstract

Swedish agriculture is facing multiple challenges due to climate change caused by the increased temperature on Earth. Climate change in Sweden is characterized by a warmer and wetter climate and extreme weather events. Today's modern crop varieties lack variation and different traits that lead to reduced yield when the weather becomes unpredictable and unstable. Landraces are a major source of various traits and genes that have disappeared in modern varieties through plant breeding. The purpose of this literature review is therefore to investigate the possibilities and limitations of landraces through a SWOT analysis to assess their potential to be used for adapting Swedish agriculture to climate change. The landraces have the strength to tolerate various abiotic and biotic stressors and adapt to local conditions through their genetic diversity. They may have a well-developed and deep root system that allows them to withstand drought. Their long straw gives landraces the opportunity to compete with weeds but is at the same time a weakness to their grain yield. Landraces have a weakness in lower yield but an opportunity for stable yield while the modern varieties have a strength in high yield and a threat in unstable yield during unfavourable conditions. The nutrient density has also been shown to be a strength in landraces because it is higher in landraces than in modern varieties. Landraces have the opportunity to contribute with traits and genetic material to adapt our crops to a changing climate. More research would be needed to develop crops that can retain the strong traits of landraces while still being able to achieve the same high yields as modern varieties.

Keywords: Landrace cereal, Traditional crop varieties, Adaptation, Sustainable agriculture

Table of contents

List of figures

Abbreviations/clarification of difficult words

Bottlenecked	Decrease the amount of genes within a population, compared with the original population, which decrease the genetic diversity within the population.
Harvest index	The quotient between the total biomass of the plant above ground and the total biomass of the kernels
RCP	Representative Concentration Pathways – gives information about the climate changes with different levels of greenhouse gas emissions.
SWOT	Strength, Weakness, Opportunities, Threats
QTL	Quantitative Trait Loci

1. Introduction

The rising temperature is causing climate changes (Wiréhn 2018; Neset et al. 2019; SMHI 2023a; IPCC n.d.). In Sweden and other Nordic countries, these changes are linked to a warmer and wetter climate and more frequent extreme weather events (Wiréhn 2018). The annual average temperature in Sweden has increased with 1,7 °C between the period years 1806-1900 and 1991-2019 (SMHI 2023b) (Figure 1) and this trend is expected to continue to increase (SMHI 2022b). Because of the increasing temperature, precipitation levels have also increased (Figure 2) from around 600 mm/year until the mid-70s to around 700 mm/year, and it is anticipated to continue to increase (SMHI 2022d). According to the RCP 4,5 scenario, for Sweden, temperature and precipitation are projected to increase with 2,6 °C for the period 2041-2070 and the precipitation will increase with 7 mm/month for the same period (SMHI n.d.a). Consequently, the frequency of extreme weather events that will increase are extreme precipitation, floods, intense winds and heat waves (Belusic et al. 2019).

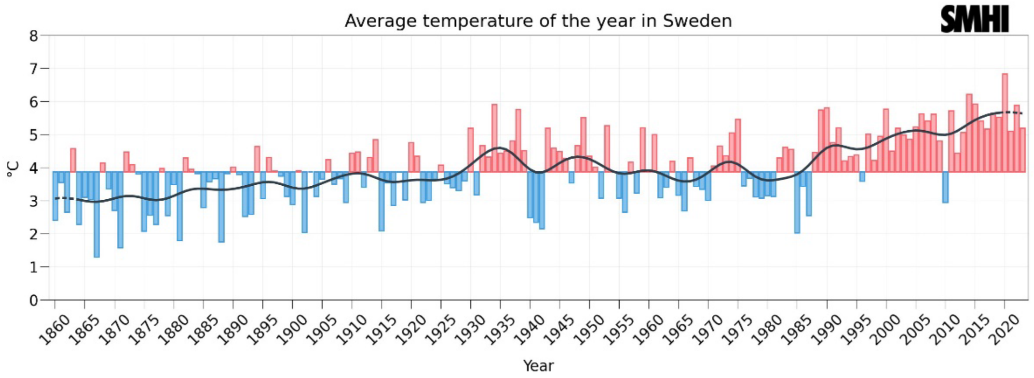


Figure 1. The bars in the chart show the average temperature per year. Red bars show higher and blue shows lower temperatures than the average for the normal period 1961-1990. The grey line shows the mean temperature. (SMHI 2022b)

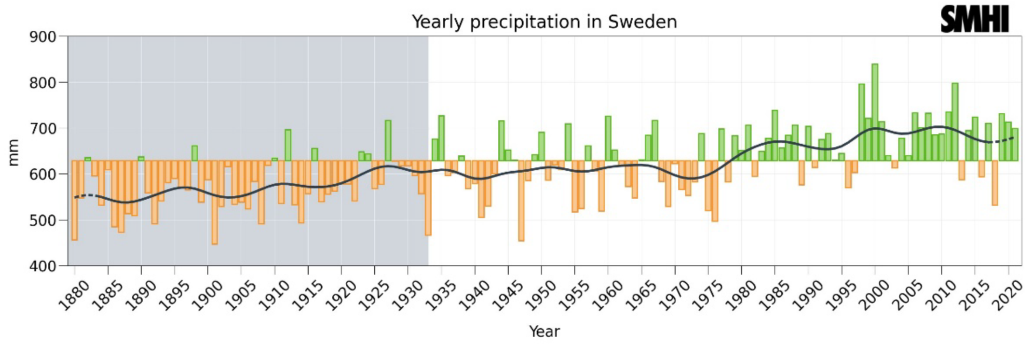


Figure 2. The bars in the graph show the total rainfall for the year. Green bars show higher and orange shows lower precipitation than the average for the normal period 1961-1990. The grey line shows the mean value. Observations before 1933 are considered to have lower reliability. (SMHI 2022a)

Climate change can have a positive and negative impact on Swedish agriculture. A positive impact of climate change in Sweden is that the vegetation period is increasing (Neset et al. 2019), which makes it possible to increase yield and harvest more than one crop per year, in a field (Wiréhn 2018; SMHI 2022c). A longer vegetation period also opens up for new types of crops and expansion of crops like winter wheat, maize and different legumes (Wiréhn 2018). A warmer climate increases the production potential of agriculture along with other factors, but simultaneously it creates challenges in agriculture throughout the year (Wiréhn 2018). The negative effect of a longer vegetation period and warmer and more humid climate is the opportunity for new weed varieties (Neset et al. 2019; Jordbruksverket 2022) and several plant diseases to be established (Wiréhn 2018; Neset et al. 2019). Because of the increased temperature and increased risk of heatwaves the water supply in plants becomes bigger which increases the risk of drought (Belusic et al. 2019) during the summer (Wiréhn 2018; Jordbruksverket 2022) which has a negative effect on yield. The number of dry days without precipitation has decreased in Sweden (SMHI n.d.b). Only during the summer in the south of Sweden, there is a little increase in the amount of dry days (SMHI n.d.b). More precipitation and a bigger risk for extreme precipitation increases the risk of floods which also has negative effects on crop yield (Jordbruksverket 2022).

In the year 2018 drought affected the Swedish agriculture and in year 2023 high precipitation was a problem during the harvest season. Our future crops must be adapted to both drought, high precipitation and extreme weather events for adaptation to climate change and the future climate in Sweden.

Today's modern varieties are homogeneous, with little genetic diversity (Gupta et al. 2020) and are bred to be broadly adapted to different climatic regions (Dwivedi et al. 2016) but not to local conditions. Due to climate change, there will be more unfavourable conditions for the crops, which means that the modern varieties are not as suitable anymore because they perform best under favourable conditions. Therefore, we need to explore other options to improve our crops' tolerance to climate change, and this opens up the possibility of exploring other options to better adapt our crops to a changing climate (Dwivedi et al. 2016; Gupta et al. 2020; Marone et al. 2021).

Landraces can be one option. According to Camacho Villa et al. (2005)

> ‘A landrace is a dynamic population(s) of a cultivated plant that has historical origin, distinct identity and lacks formal crop improvement, as well as often being genetically diverse, locally adapted and associated with traditional farming systems’

This definition of landraces points to what distinguishes them from today's modern varieties. The landraces have not undergone any plant breeding as the modern varieties have. Instead, it is the farmer, the cultivation system and natural selection that have shaped the landraces into a heterogeneous crop population (Murphy et al. 2005). In the 20th century the majority of farmers started to grow modern varieties instead of landraces, and today around 50 farmers, mostly organic farmers, grow landraces in Sweden (Ortman et al. 2023b). These farmers grow landraces because of different traits of landraces they think are favourable in their cultivation system. Traits are “any morphological, physiological or phenological feature measurable at the individual level, from the cell to the whole-organism level, without reference to the environment or any other level of organization.” (Violle et al. 2007). Some examples of these favourable traits in landraces, according to the farmers are genetic diversity, local adaptation, competition, growing well in marginal conditions and tolerance to different stresses (Ortman et al. 2023b). These different traits of landraces are important when we need to adapt our crops to climate change which creates a more unstable climate.

1.1 Aim

This literature study aims to identify traits of landraces with a focus on landrace cereals, because cereals, together with grass, are the most grown crop in Sweden (Jordbruksverket 2024), and discuss their strengths, opportunities, weaknesses and threats in providing better adaptation of Swedish agriculture to climate change.

2. Method

This work is a literature review where academic and scientific literature has been studied in both Swedish and English. The literature has mainly been found through searches in Google Scholar, Primo and also through references in scientific articles. Google Scholar was the main search engine due to its wide range of different scholarly articles. Different search terms that have been used are "landrace", "climate", "climate change", “Sweden” and "landrace cereal" which have been combined in different ways.

A SWOT analysis was chosen to be carried out in order to easily categorize the different traits of landraces in relation to climate change. SWOT – analyses stand for Strength, Weakness, Opportunities and Threats. SWOT – analysis is commonly used by businesses, companies and organizations to develop, plan and evaluate different projects (Projektledning 2022). The method can also be used to find solutions to problems (Renault 2017) as the method is educational and contributes to opportunity thinking (Frankelius et al. 2015) and increased understanding (Projektledning 2022). The SWOT analysis involves identifying strengths, weaknesses, opportunities and threats to find positive qualities that can work together and potential problems that need to be highlighted (Renault 2017).

Using this framework, an analysis of the landraces' strengths, weaknesses, opportunities and threats has been done to identify the potential for landraces to be used for climate adaptation in Swedish agriculture.

3. Results and Discussion

In the SWOT analysis different traits and effects that landraces can contribute to the climate adaptation of modern agriculture were identified. These traits were divided into four different categories. Firstly, based on their diversity and adaptability: where the landraces adaptability to the local climate and adaptation to abiotic and biotic stress will be presented and discussed together with their possibilities to contribute genetic material for breeding new varieties. This will lead us to the second category below ground growth traits of landraces focusing on the root system and its ability to absorb water and nutrients. The underground vigour leads us to the third category, above-ground vigour which will discuss the strength and weakness of the long straw of landraces, their ability to compete with weeds, and their early growth of roots and shoots. All these different traits lead us to the fourth and last category about landraces ability to produce high and stable yields, which is the most important trait for food security in connection with climate change, both in Sweden and throughout the world. After the presentation and discussion of the traits of landraces, a summary of their strengths, opportunities, weaknesses and threats will be presented based on the swot analysis framework. Finally given the result of the swot analysis a conclusion will be drawn regarding their potential for climate adaptation in Sweden.

3.1 Diversity and Adaptability

3.1.1 Genetic material and diversity within landraces

Through plant breeding of modern varieties different favourable alleles have been selected, which has led to reduced crop genetic diversity (Haudry et al. 2007; Dwivedi et al. 2016; Marone et al. 2021). One example is Emmer which is a primitive species from the beginning of farming and through plant breeding; the genetic diversity of wheat has decreased by 69% and that of durum 84% compared to Emmer (Haudry et al. 2007). These modern varieties of crops are considered to be bottlenecked, which means that they have lost genetic diversity, due to this selection process in breeding (Haudry et al. 2007; Marone et al. 2021) for high yield and quality in high input systems. Landraces have not been developed through modern breeding, instead, they have been developed by the farmer and natural selection (Murphy et al. 2005) and that is why landraces have maintained a high level of genetic diversity (Reynolds et al. 2007).

There is a threat to the genetic diversity in landraces (Gupta et al. 2020; Mir et al. 2020). One reason for this is that we have replaced the landraces with modern varieties, which has reduced their cultivation, which has caused a decrease in genetic diversity within landraces through genetic erosion (Gupta et al. 2020; Mir et al. 2020). Genetic erosion is the loss of genetic diversity within a population through genetic drift (Woodruff 2001). Genetic drift occurs when the population is small and chance determines which genes are passed on, which means that genes with a low frequency can disappear, which means reduced genetic variation (Nationalencyklopedin n.d.). The result of genetic erosion in landraces is a decrease in genetic diversity (Dwivedi et al. 2016; Gupta et al. 2020; Mir et al. 2020).

The loss of diversity is becoming important when we need to adapt our crops to climate change (Dwivedi et al. 2016). That's why we need to preserve landraces, to save them from genetic diversity loss, maintain food security and find new solutions to climate change (Gupta et al. 2020; Mir et al. 2020). This can be done through in-situ or on-farm conservation (Gupta et al. 2020; Mir et al. 2020; Raggi et al. 2022). Today, in Sweden, seeds of landraces are exchanged between farms, through seed networks like Allkorn which is a national Swedish seed-swapping association (Ortman et al. 2023b). When a farmer replaces a modern variety with a landrace, it is possible to mitigate the risks of climate change and at the same time increase the agricultural biodiversity through genetic diversity in the cultivation system which will increase the resilience of agriculture to climate change (Kamal 2021). Agricultural biodiversity is part of the diversity and variation of all living things that contribute directly or indirectly to agriculture (Mijatovic et al. 2012). It gives ecosystem services and enables adaptation to climate change (Mijatovic et al. 2012).

Landraces have the strength to tolerate the biotic stress of pests and disease because of their genetic diversity and heterogeneity which can buffer the effect of the disease or delay the invasion together with natural enemies (Ortman et al. 2023b). Different genotypes within the population react differently to different stresses, some do better than others, which makes the population as a whole tolerant to the biotic stress (Leino 2017). This has been described by farmers (Ortman et al. 2023b). A crop with many genes has a more durable resistance to disease than crops with few genes (Murphy et al. 2005). A plant with several genes that can recognize a disease means that the disease cannot become established. If there is only one gene that can recognize the disease, the disease can mutate and establish itself in the plant without the plant recognizing the disease (Newton et al. 2009). Increasing genetic diversity in a monoculture can limit the severity of yield losses due to plant diseases (Murphy et al. 2005). Landraces carry resistant genes that can be used to increase tolerance to various diseases (Marone et al. 2021). Another trait in landraces for biotic stress is the long distance between the flag leaf and ear which prevents spores of disease from coming to the ear (Ortman et al. 2023b). Landraces also have problems with diseases. Farmers have described problems with soil-borne diseases and seed-borne diseases, for example, dwarf bunt. Reducing the spread of seed-borne diseases during seed exchange was considered a challenge according to the farmers (Ortman et al. 2023b). This could be a potential threat to the cultivation of landrace cereals.

QTL mapping has been used to some extent to identify genes in landrace cereals for tolerance and adaptation to abiotic and biotic stress (Marone et al. 2021). Genes for drought tolerance, salinity tolerance and rust resistance have been found in landraces through QTL mapping (Marone et al. 2021; Adhikari et al. 2022). This shows that the genetic diversity in landraces can be used for plant breeding and that it can be further investigated to identify genes of importance to develop our crops to climate change.

In summary, landraces contain a large source of genes for important traits (Gupta et al. 2020; Marone et al. 2021)). The genetic variability of landraces includes beneficial traits with an opportunity for plant breeding (Dwivedi et al. 2016).

3.1.2 Local adaption

Local adaptation describes a process by which a given population develops better adaptability to its specific environment compared to other individuals within the same species (Corrado & Rao 2017). The genetic diversity of the landraces allows them to adapt to the local environment and cultivation system (Ortman et al. 2023b) which is a strength. The adaptation of the landraces to the local environment, the cultivation system at the site, and the natural selection for specific traits according to site-specific conditions explain the vast number of different landraces cultivated (Newton et al. 2011). According to farmers that grow landraces, it takes 3-4 years for landraces to show evidence of trait adaptation in a new environment (Ortman et al. 2023b), but no scientific evidence was found to support the farmers' observations. As landraces and modern varieties adapt, their genetics continuously improve (Newton et al. 2011). Landraces have many genotypes in different frequencies within the population (Leino 2017) as shown in Figure 3. The different genotypes react differently to different environments and types of biotic and abiotic stress, which means that the landrace as a population can cope with variations of different stressors (Corrado & Rao 2017; Leino 2017). A study by Reynolds et al (2007) also found significant phenotypic diversity and genetic differences between landrace populations and within landrace populations. The phenotypic plasticity, the ability to adapt the phenotype to have the capacity to handle a variety of environmental conditions, will become important with more unstable and extreme weather conditions due to climate change (Pilling 2015).

Figure 3. The landrace on the left is heterogeneous and has a greater intra-variety variation compared to a modern variety on the right that is homogeneous. Photo: Karin Gerhardt.

Corrado & Rao (2017) believe that in order to achieve more climate-resilient agriculture, the ability of plants to adapt to climate change is an important trait in plant breeding, and identifying and understanding the genetic basis for local adaptation in landraces will help us develop new varieties that are well adapted to local conditions. This is of particular importance when we need to develop an agriculture that uses less inputs to reduce the environmental impact of agriculture (Corrado & Rao 2017). Examples of environmental impact can be eutrophication, nutrient leakage and the use of chemical pesticides. In organic farming, less inputs, in the form of chemicals, are used compared to conventional farming. In this context, local adaptation is particularly important for cultivating a competitive crop with stable yield and high nutritional value (Leino 2017; Moreira-Ascarrunz et al. 2016).

At the same time, Pilling (2015) describes a threat of climate change to landraces and other crops when the climate changes rapidly. Landraces that are adapted to certain environments in different parts of the world will no longer be adapted to these environments due to climate change. This means that farmers may have to replace the landraces with other landraces, from another part of the world, that are better adapted to the new conditions. Pilling (2015) means that there are limits to how much a local variety can adapt to the climate, especially when climate change is increasing rapidly. This means that even if the landraces have the ability to adapt to new environments they cannot do it as much as needed, fast enough, if the climate is changing so rapidly.

In summary, it has been described above how the genetic diversity of landraces gives them the ability to adapt to their environment and this leads us to the different traits of landraces (Figure 4) that are affected by their genetic diversity and the ability to adapt.

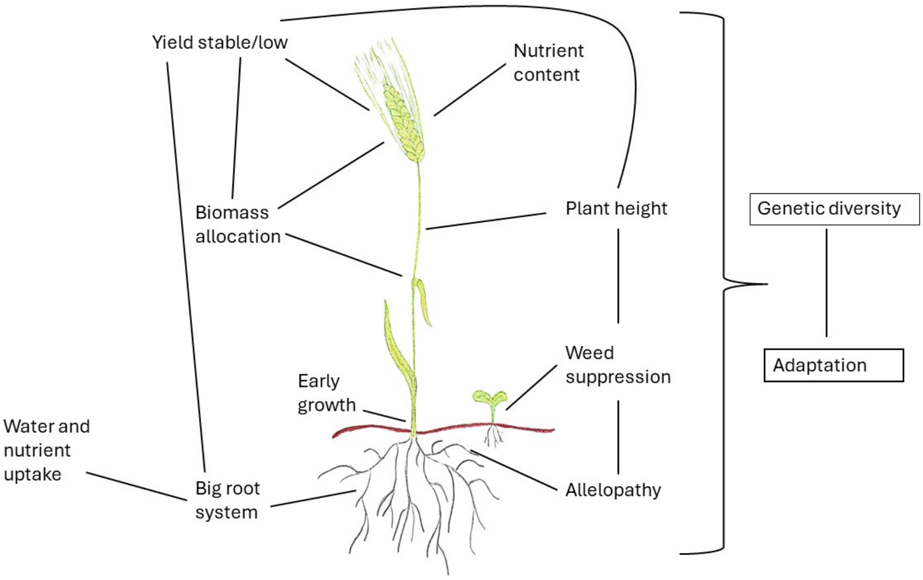


Figure 4. Mind map over the traits of landraces and how they affect each other. Illustrator: Linnea Berggren Sjögård

3.2 Underground vigour

3.2.1 The root system and ability for water and nutrient uptake

Bektas et al. (2016) in Turkey and Waines & Ehdaie (2007) in the USA show in their studies that landraces, compared to modern wheat varieties, have greater total root biomass, superficial root weight and deep root weight. In terms of deep root weight, landraces had two times more deep root weight than modern wheat (Bektas et al. 2016). Below 60 cm depth, landraces have better nutrient uptake than modern varieties (Reynolds et al. 2007). Waines & Ehdaie (2007) also show that the root system of modern varieties is too small to absorb the optimal amount of water and nutrients they need for maximum grain yields. Other sources that show this has not been found. If this is the case, there is a possibility to develop the root system of modern varieties in order to increase their yield ability even more, and landraces are one opportunity to do that.

The root system is important for a plant's water and nutrient uptake and components that affect crop yield (Waines & Ehdaie 2007). With a larger and deeper root system, covering a wider and deeper soil profile, the plant can acquire resources more effectively and have an increased grain yield as a result (King et al. 2003). The connection between the root system and grain yield has also been shown in studies by Sarker et al. (2005) and Waines & Ehdaie (2007). At high temperatures and drought, there is a shortage of water in the upper part of the soil profile, which places higher value on a well-developed and deep root system. Landraces, fitting this description (Bektas et al. 2016) have the ability to extract water from the deepest part of the soil profile, which in a study by Reynolds et al. (2007) in Mexico was 120 cm deep. According to Bektas et al. (2016), the deep and dense roots of landraces play an important role in reducing the effects of drought and rainy conditions because their root system is large and well-distributed over the entire soil profile and can more efficiently capture water and nutrients throughout the soil profile, both shallow and deep (Bektas et al. 2016). The strength of larger root systems of landraces for more efficient water and nutrient uptake is likely to have a greater value with the higher temperatures and increased water stress predicted to result from climate change and is therefore an opportunity in plant breeding (Dwivedi et al. 2016). In the literature, it is not clear how landraces can cope with heavy rain, which will increase more than drought, due to climate change. One thought is that their well-developed and well-distributed root system can increase the drainage capacity of the soil, which can reduce the risk of floods.

As previously stated, landraces have evolved in a time before modern agriculture came along (Leino 2017). This has of course meant that landraces have developed in environments with low nutrient availability, and no artificial fertilizer, which has meant that they have been developed for cultivation systems with little access to nutrients (Newton et al. 2011), explaining their extensive root system. In addition to a well-developed root system, the ripening time is also important for the uptake of nutrients in the form of nitrogen in the landraces. Their ripening time is often later than for modern varieties (Newton et al. 2011). When the nitrogen supply is limited, it becomes necessary for nitrogen uptake to take place through mineralization of soil organic matter, but this process is time-consuming and does not always meet the plant's nitrogen needs. The landraces that ripen later than modern varieties have time to absorb more nitrogen during the growing season, if there is enough water. This makes them more suitable for cultivation where nitrogen inputs are low (Newton et al. 2011). At the same time, a study by

(Elbasyoni et al. 2019) in Egypt shows that landraces have lower nitrogen use efficiency compared to modern varieties of wheat. A study by Ortman et al. (2023a) in Sweden, showed equal to or higher nutrient use efficiency in modern varieties compared to landraces. According to this, landraces have lower nutrient use efficiency than modern varieties.

In Ortman et al. (2023b) according to interviews, farmers, that grow landraces, they apply less nitrogen compared to modern varieties because the landraces cannot take advantage of high inputs of fertilizer. Because of the landraces' ability to grow in low input conditions, this is a way for organic farmers without livestock to decrease their cost for fertilizer. It is enough to apply 80-120 kg of nitrogen, according to farmers, to get a yield with high protein levels (Ortman et al. 2023b). In an experiment in Sweden by Ortman et al. (2023a), 100kg of nitrogen organic fertilizer was added, which affected both the landraces and the modern varieties in the same way and produced higher grain yield compared to non-fertilized plots.

3.3 Above-ground vigour

3.3.1 Growth of shoots

Landraces show a higher shoot biomass than modern varieties. In the study by Bektas et al. (2016), landraces had a 32,8% increase in shoot biomass, over two years, compared to modern varieties. The amount of shoot biomass has a strong positive correlation with root biomass, number of fertile seeds, root length and plant height (Bektas et al. 2016), which means that the amount of shoot biomass increases with these traits. At the same time, the harvest index was negatively correlated with shoot biomass (Bektas et al. 2016). This shows a weakness with the high-shoot biomass within landraces. Shoot weight has decreased in the transition from landraces to modern varieties (Bertholdsson & Kolodinska Brantestam 2009).

Increased early ground cover and early growth is a strength of landraces which makes them more resilient to extreme weather (Ortman et al. 2023a). Especially for drought adaptation (Reynolds et al. 2007; Bertholdsson & Kolodinska Brantestam 2009). Early growth and ground cover reduce the evaporation from the soil and make more water available for the plant. Total biomass and grain yield are positively correlated with early vigour (Bertholdsson & Kolodinska Brantestam 2009). The early growth and early ground cover have positive effects on drought tolerance in landraces, but it is unclear if that correlates with the increased shoot biomass.

3.3.2 Plant height

When you compare landraces and modern varieties visually, the biggest difference is the plant height (Figure 5) - the landraces are considerably taller than the modern varieties (Leino 2017; Bektas et al. 2016). Through the natural selection of landraces, the long straw has not been shortened, which may be due to its use by the farmer as feed, craft, and building material (Leino 2017). In some places, landraces are still grown because of their high straw yield (Bektas et al. 2016; Leino 2017). If a plant with a shorter straw had been developed in a landrace population, it is doubtful that it would have survived among the tall straws within the population (Leino 2017). This is because the length of the straw gives landraces the important trait for competitiveness (Murphy et al. 2008), which may have contributed to the preservation of the long straw.

Figure 5. Shows the difference in height in spring wheat between a landrace to the left and a modern variety to the right. Photo: Tove Ortman

The weakness of the long straw is that it increases the risk of lodging (Figure 6) (Leino 2017). However, this was not perceived as a weakness until the landraces were grown in modern high-input systems (Leino 2017), because the risk of lodging increases with high nitrogen availability and is reduced with low nitrogen fertilization (Ortman et al. 2023a; b). When modern conventional agriculture was introduced with high inputs in the soil, in the form of increased nitrogen supply, and an increased plant density, the risk of lodging increased (Leino 2017). In a study by Murphy et al. (2008) in Washington state USA, no lodging was observed in 63 cropping systems, while in a study by Diederichsen et al. (2013) in Sweden, landraces showed a tendency to lodge compared to modern varieties. Early lodging can cause quality problems in landraces (Diederichsen et al. 2013).

Figure 6. Lodging in a landrace to the right and a modern variety to the left with no lodging. Photo: Tove Ortman

Large amounts of precipitation can increase the risk of lodging. Landraces that have a higher tendency to lodge compared to modern varieties will be affected by lodging to a greater extent in the event of increased precipitation and extreme weather events caused by climate change. If landraces are to be used for breeding, improvements should be made to reduce the risk of lodging (Diederichsen et al. 2013).

According to a study by Wilson (2024) in Sweden and Swedish farmers (Ortman et al. 2023b), landraces have the opportunity to be used for intercropping to increase the production of legumes and cereals in Sweden and to preserve genetic diversity for adaptation to climate change. The plant height of landraces can be a problem because it is unclear if the differences in plant height of the crops are a disadvantage for intercropping (Wilson 2024). At the same time, farmers describe the competitiveness, of the long straw, of landraces as a good thing in intercropping (Ortman et al. 2023b). According to Maitra et al. (2021) crops with different morphological traits should be selected in intercropping to complement each other.

3.3.3 Weed competition

Landraces are mostly grown in organic farming (Leino 2017; Ortman et al. 2023b) where herbicides are not used, which has led to an increased interest in landraces as plant material that can outcompete weeds (Leino 2017). The changing climate will increase the opportunity for new weed species to establish themselves in Sweden (Jordbruksverket 2022) because they, like all other vegetation, will benefit from a longer growing season (SMHI 2022; Wiréhn 2018). These new weeds are likely to require innovative approaches to manage and for this reason, landraces have the opportunity to be used for effective weed suppression. In a study by Carranza-Gallego et al. (2019) in the south of Spain, it was 40-64% lower weed density in landraces compared to modern varieties.

The strength of the long straw length of landraces is that it gives them the opportunity to compete with weeds in the field (Figure 7) (Leino 2017; Murphy et al. 2008; Andrew et al. 2015). Because the long straw gives them the high ability to compete for sunlight (Ortman et al. 2023b) by shading the weeds (Andrew et al. 2015). In a field study by (Ortman et al. 2023a) Dala lantvete and Ölandsvete had the best ability of weed suppression. This trait is beneficial for the farmer as it reduces the need for mechanical control and the intensity of possible weed control.


© Dylan Wallman

Figure 7. Weeds in landrace to the left and weeds in modern variety to the right. Photo: Dylan Wallman.

The straw length of landraces is negatively correlated with weed weight (Murphy et al. 2008), which means that as plant height increases, the number of weeds decreases. Murphy et al. (2008) suggest that plant height should be selected for better weed suppression ability in plant breeding. The long straw is not the only trait that contributes to the ability of weed suppression (Andrew et al. 2015). Other traits that affect the weed suppression is leaf area index, early vigour, seedling growth and allelopathic traits (Bertholdsson 2005; Murphy et al. 2008; Andrew et al. 2015).

Allelopathy

Some farmers use landraces as “cleaning crops”, to clean the field of weeds. This is related to their long straw, but also their allelopathic traits (Ortman et al. 2023b). It has been found that landraces have the strength of some allelopathic effect on weeds and weed suppression (Bertholdsson 2004; Leino 2017). In a paper, Ortman et al. (2023) interviewed farmers who described the landraces with allelopathic abilities:

> …it is something about the roots [of the landrace] that senses the weeds and make sure that the weeds don’t make mischief.

A study by Bertholdsson (2004) shows that potential allelopathic ability has decreased as new high-yielding varieties are released. There are several possible reasons for the decline in allelopathic ability, two of which are mentioned by Bertholdsson (2004). One is that the physiological costs of high levels of allelochemicals in root exudate can counteract the high yield valued by traditional breeding. The second, in relation, is that the genes that control the exudation of highly allelopathic landraces have gradually been diluted by plant breeding, which has been selected for high yield when resources are in high supply.

In the same study by Bertholdsson (2004), two Swedish barley varieties had the highest allopathic activity. These two varieties are related to different landraces, which shows that allopathic properties are present in the germplasm of landraces. This means that landraces are a source of traits for allelopathy and weed suppression which is useful in organic farming. At the same time, weed suppression of landraces can be used outside organic farming to reduce the use of herbicides, which have negative effects on biodiversity (Bertholdsson 2005; Andrew et al. 2015). It is important to select for these traits of weed suppression for the future problems that may arise due to climate change, such as the proliferation of more, or different weeds.

3.4 Yield

3.4.1 Allocation to non-grain tissues

Landraces have the weakness of a low harvest index, which means that the plant spends more energy on creating biomass in the form of a long straw instead of investing in many kernels (Leino 2017; Newton et al. 2011). This means a strong negative correlation exists between the length of the straw and the grain yield. Through the breeding of modern varieties, the harvest index has increased, which means that the plant has redistributed its resources of biomass. This resulted in a shorter straw and a larger grain yield (Leino 2017). This is a reason for higher yield in modern varieties compared to landraces (Ortiz et al. 1998). According to Murphy et al. 2008, the variations in the yield of cereals are due to the traits of plant height, leaf area index, juvenile growth and 1000 kernel weight which has a positive effect on the yield of landraces, while coleoptile length has a negative effect on yield. As previously noted, the large root biomass of landraces increases their water and nutrient uptake and have a positive effect on yield (Waines & Ehdaie 2007). In lentil landraces, plant height accounts for 85% of the yield variation, indicating that plant height is an important trait in the selection of genotypes for drought tolerance (Sarker et al. 2005). According to Sarker (2005), improving taproot length and the number of lateral roots in lentils does not improve yields. This is the opposite of what Waines & Ehdaie (2007) reported. This may be because the effect of the root system on yield differs between crops of landraces. Both of these studies agree that plant height is an important trait for yield, however. The negative relationship between plant height and the amount of grain yield in landraces leads us to question their yield stability.

3.4.2 Quantitative yield and stable yield

Today, comparing harvest levels between landraces and modern varieties is difficult. Today's agriculture is very different from the past. During the 1900s, changes took place in the form of improved machinery that provided better and more efficient tillage. Fertilizer strategies changed when artificial fertilizers were introduced. At the same time, chemical pesticides changed cultivation strategies in agriculture. Landraces were bred before we had these major changes in agriculture, which means that they do not react positively to today's modern, high-input, cultivation systems. This makes it difficult to compare the yield levels between modern varieties and landraces as they have been shaped and grown in completely different systems (Leino 2017). Modern varieties outyield landraces under favourable, high input and non-stress conditions while the ability of landraces to adapt to abiotic and biotic stress gives them a higher yield than modern varieties in low-input cropping systems (Dwivedi et al. 2016).

A strength of landraces is therefore their stable yields (Dwivedi et al. 2016; Gupta et al. 2020; Leino 2017) which is due to their genetic variation within the population, conferring that landraces has the ability to tolerate different types of abiotic and biotic stress and environmental influences (Leino 2017; Raggi et al. 2022). In a 2 year experiment in Yugoslavia by Denčić et al. (2000) the yield of modern varieties and landrace was compared to each other during optimal and drought conditions. The yield for modern varieties was 7.79 t/ha under optimal conditions while the yield for landraces was 4.35 t/ha. This supports claims that landraces have a lower yield under optimal conditions. During drought stress, the yield for modern varieties was 4.75 t/ha while the yield for landraces was 4.11 t/ha (Denčić et al. 2000). This shows that there is no major difference in yield between modern varieties and landraces during drought stress. Landraces, however, have more or less the same yield level regardless of whether the conditions are optimal or stressed, which shows that they can provide stable yields. In another field study by Ortman et al. (2023a) in Sweden, the grain yield, among other traits, was compared between wheat of modern varieties and landraces in organic farming with no fertilizer added and 100 kg/ha of fertilizer added. It was shown that modern varieties and landraces had about the same yield under low input conditions. Under high input conditions, modern varieties had higher yields. The experiment was done in two different places. Two landraces and one modern variety, out of three modern varieties, showed stability in yield between these two places (Ortman et al. 2023a). This could demonstrate the landraces' ability for local adaptation.

Murphy et al. (2005) found a study by Corte et al. (2002) where they grew dry beans in Brazil in bulk populations under different conditions. It turned out that the grain yield increased by 2.5% per generation, above the mean for the parents (Corte et al. 2002). From that, Murphy et al. (2005) make the assumption that in environments with a fluctuating biotic and abiotic influence on the crop, natural selection will favour the high-yielding genotypes. This proposition would appear to favour modern, high-yielding varieties, but it has been shown in the studies by Denčić et al. (2000) and Ortman et al. (2023a) that landraces and modern varieties yield about the same under low inputs and stresses, like drought. More studies that may support the proposition by Murphy et al. (2005), except for Corte et al. (2002), have not been found.

3.4.3 Nutritional content

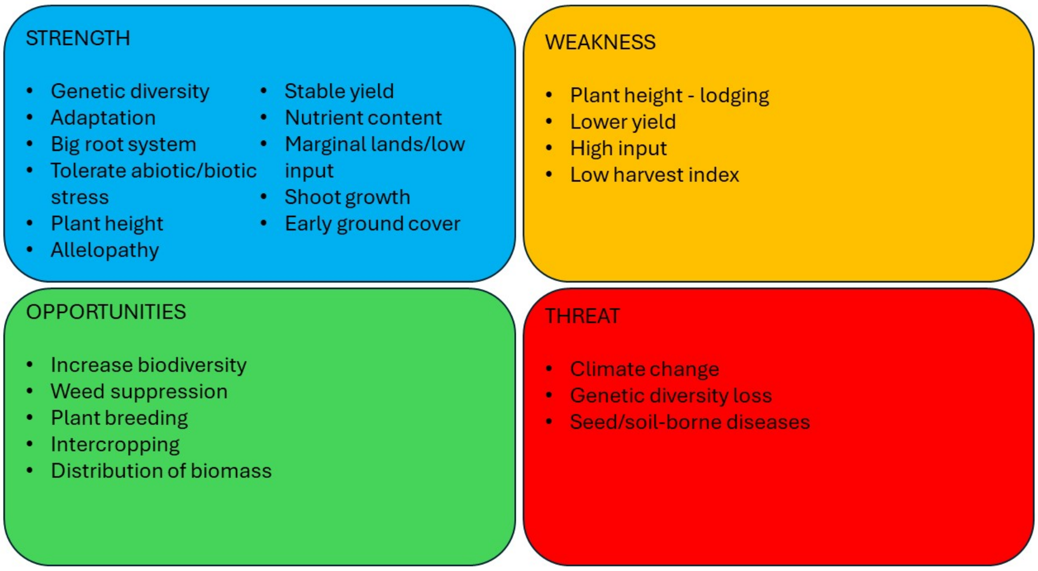
The nutrient content of modern varieties has also been reduced by plant breeding (Newton et al. 2011). Because of climate change, we need to make more effective use of the land that we are growing. One way to do that is to increase the nutrition content in our crops for better food security. The nutrient content in our food and the amount of yield are important components for nutritional and food security (Moreira-Ascarrunz et al. 2016; Wezel et al. 2020). Landraces have the strength of containing more minerals, especially iron and zinc compared to modern varieties (Wezel et al. 2020; Adhikari et al. 2022). These two minerals are in deficit in our diet (Moreira-Ascarrunz et al. 2016). The content of copper and magnesium is also decreasing in today's modern varieties, but at the same time, our intake of copper and magnesium is above the recommended intake (Moreira-Ascarrunz et al. 2016). A Swedish study by Moreira-Ascarrunz et al. (2016) shows that the nutrient density was higher in old varieties and landraces compared to modern varieties in Sweden. This is shown by the fact that 270g of landrace wheat is needed to cover the recommended intake, while over 300-350g of modern wheat is needed to cover the recommended intake of iron, zinc, copper and magnesium, which was examined in the study. Through plant breeding, we have therefore prioritized yield over nutrient content (Morris & Sands 2006). When modern varieties are to be used, the recommended intake recommendations need to be increased in order to get the right amount of the minerals that the study examined, especially iron and zinc (Moreira-Ascarrunz et al. 2016). The study by Moreira-Ascarrunz et al. (2016) and another study by Hernandez-Espinosa et al. (2020) show that landraces are a good source for breeders to achieve a crop with both nutritional quality and density.

The study by Moreira-Ascarrunz et al. (2016) also shows the relationship between yield and nutrient density. The genotype with the highest yield did not have the highest nutrient density, while the genotype with the lowest yield had high nutrient density. Landraces are a good source of phytonutrients accompanied by optimal micronutrient concentrations; emmer, in particular, is a rich source of protein, iron, and zinc (Wezel et al. 2020). Landraces are, therefore, an important source for improving the nutrient content of cereal crops (Morris & Sands 2006; Newton et al. 2011; Moreira-Ascarrunz et al. 2016; Hernandez-Espinosa et al. 2020).

3.5 The SWOT Analysis Results Summary

In summary, the different traits of landraces have been identified and discussed to determine whether each trait is a strength, weakness, opportunity or threat. In Figure 8, the different traits are divided under each category: strength, weakness, opportunity and threat. Some traits have been difficult to categorize as strengths or opportunities since strength can also be an opportunity for the landrace to be used for adaptation to climate change. One such trait is that they grow well in marginal areas with low inputs. This could also be seen as an opportunity for landraces to grow more under such conditions, but at the same time, it is a strength to be able to grow under such conditions. One trait that is both a strength and a weakness is the long straw which provides a strength in the form of good competitiveness but a weakness in the form of an increased risk of lodging. The strength of competitiveness in the plant height, together with allelopathy, gives landraces the opportunity to be used for weed suppression. This makes it possible to also consider weed suppression as a strength. Their growth of shoots is categorized as a strength as it is beneficial for the plant's height, roots and seeds, but negative for the landrace's ability to give a high yield. From a yield perspective, shoot growth would instead be categorized as a weakness.

Whether climate change is a threat to landraces can also be debated. It has been categorized as a threat because, according to Pilling (2015), landraces cannot adapt their traits sufficiently and quickly enough, with an increase in the rate of climate change. The fact that they would be threatened by climate change does not mean that they have the opportunity to be used for adaptation to climate change. At the same time, they are no more threatened by climate change than any other crop. However, they possess great genetic diversity that we need to take advantage of because that genetic diversity is threatened due to human influence, but we also have the opportunity to preserve it.



STRENGTH

- Genetic diversity
- Adaptation
- Big root system
- Tolerate abiotic/biotic stress
- Plant height
- Allelopathy
- Stable yield
- Nutrient content
- Marginal lands/low input
- Shoot growth
- Early ground cover

WEAKNESS

- Plant height - lodging
- Lower yield
- High input
- Low harvest index

OPPORTUNITIES

- Increase biodiversity
- Weed suppression
- Plant breeding
- Intercropping
- Distribution of biomass

THREAT

- Climate change
- Genetic diversity loss
- Seed/soil-borne diseases

Figure 8. The SWOT analysis of landraces' ability to contribute to climate adaptation in Swedish agriculture. Illustrator: Linnea Berggren Sjögård

4. Conclusion

Different strengths, opportunities, weaknesses and threats have been identified in landraces to appraise their potential to help adapt Swedish agriculture to current and future climate change.

Today's modern varieties have been developed for one-sidedness, large geographical areas and high yields, which has meant that we have lost large parts of genetic material and traits that today remain in landraces. Landraces have the potential to contribute with traits and genetic material for plant breeding to find new or improved varieties that can cope with the unstable and more extreme weather conditions that come with climate change. Their ability to provide stable and nutritious harvests despite low access to nutrients is positive from an environmental point of view as less input is required.

A problem with landraces is their low yield level, as they produce more or less the same amount of harvest regardless of conditions. More research would be needed on how to take advantage of the positive traits of landraces in the form of genetic diversity, local adaptation, well-developed root system, weed suppression, and stable and nutritious yields while maintaining the high yields of modern varieties or increasing them further in order to ensure sufficient food production.

Questions that need to be investigated in order to exploit the potential of landraces for adapting Swedish agriculture to climate change:

- When it comes to the root system of the landraces, there was a lot of information about how landraces can cope with drought in a good way, thanks to their well-developed root system. Less information was found about how they can cope with large amounts of rain. A question is whether and how landraces can cope with heavy rain.

- It was found that it takes 3-4 years for a landrace to adapt to a new environment, but no scientific evidence was found. How long does it take for a landrace to show signs of adaptation to a new place, in Sweden?

- It was found in the literature that natural selection may favour high-yielding genotypes (section 3.4.2). Landraces show evidence of stable yields, but does the yield also increase from year to year when they adapt to the cultivation site?

- Landraces can be grown in systems with low nutrient inputs. What fertilizer amounts and fertilizer strategies are required to get the optimal yield of landraces in Sweden? What is the optimal yield for landraces?

With this information, it may be possible to go further to see how breeding can combine traits of landraces and modern varieties to be able to produce a high yield despite climate change.

Most of the studies found in this literature study, have been conducted in other countries and often in countries with climates that differ from the Swedish climate. It would be of great benefit to answer these questions with a focus on Sweden and Swedish conditions for adapting Swedish agriculture to climate change.

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