



NEW VALUE LANDSCAPES FOR PLANT PROTEIN PATHWAYS

D2.1 – Database of varietal robustness for future proofing

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Author(s)/Organisation(s)	Carl- Otto Ottosen, Aarhus University
Contributor(s)	Muhammad Ashan Asghar, Aarhus University, Ewen Mullins & Richard Lynch, Teagasc, Mosab Halwani, ZALF & Massimo Blandino, UNITO
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Abstract:	This document is an actionable report detailing the database of varietal robustness for future proofing effects of climate stress on faba beans and other legume species. It includes data on phenological responses, growth, yield, and seed quality of these legume species to abiotic stressors.

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22	Kerry Luxembourg S.á.r.l.	KERRY	Luxembourg

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Abstract

Climate stress, encompassing factors like heat, drought, and cold, significantly affects faba beans and other legume species such as chickpeas and lupines. One of the challenges is the understanding of the physiological, biochemical, and genetic responses of cool-season legumes to concurrent heat and drought stresses, which might facilitate the creation of robust, climate-resilient cool-season legumes. Furthermore, the different legume species vary in their responses to single stresses both in short and long term responses and the genetic variation can be significant. Accessing germplasm can also be a challenge, as many suppliers have limited number of varieties (as highlighted in [Gaps in the EU Plant-Based Protein Value Chain](#)) and sourcing from various gene banks while possible, usually requires a long period of propagation to obtain sufficient number of seeds for experimental purpose. Furthermore, older accessions are now well documented in terms of collection site and almost always with lack of genetic background both in terms of pedigree and genetic sequence. So a long term roadmap is needed to secure a plethora of high quality legume crops for the market. The aims of the present report and associated database are to give an overview of the stress effects of some of the key legume species and how to perform selection linked to the possibilities of accessing germplasm of different origins and accessible gene bank depositories. The focus is to review the effects of single and combined stresses and uncover the combination effect of climate change related stresses on legumes and highlight challenges and possible solutions and roadmaps to secure a supply of plant based food. The specifications concerning the database are outlined in chapter 5 and a manual for the database is enclosed in the appendix.

1. Introduction

Abiotic stresses represent a major constraint to agricultural production with temperature and drought stress, and is one of the primary determining factors for yield losses (Siddiqui et al., 2015). Usually, the negative effects of extreme temperatures on plants are seen after continuous cold or heat for a given period but even smaller deviations from optimal conditions affect plant growth rate. The optimum growth temperature for most temperate legumes such as faba beans and chickpeas is between 10 and 30 °C, and the temperatures below or above these may result in cold and heat injury to the crop, respectively. Early spring or late autumn sown crops may encounter low temperatures and sudden frosts and drought in autumn and unusually low temperatures during winter and early spring result in significant yield reductions. Similarly, crops cultivated in the early summer season may be exposed to high temperatures (Zhou et al., 2015), which can have a negative impact on plant growth and the economical yield (Branca et al., 2013).

Crops will be adversely affected by increasing high ambient temperature, thus becoming more

vulnerable with global warming (Siddiqui et al., 2015). Early spring and autumn-sown crops, such as faba bean, may experience low temperatures at the beginning of the growing season and high temperatures during the flowering phase (Stoddard et al., 2006). Thus, crops cultivated in regions with extensive temperature fluctuations often associated with climate change will likely experience a wide range of temperature changes and suffer a combination of drought, cold and heat stresses during the vegetative phase and more frequent heat and drought stress during the flowering phase typically resulting in reduced flowering and reduced yield. There are very few if any research-based information of the effects of multi-stress conditions on the quality and composition of the seeds in legumes, which underlines the need for an understanding of the connection between single or combined climate stress.

Screening for stress response of a panel of a (large) number of legume genotypes requires effective criteria to identify potentially high value material within the collection. The most sensitive component for detecting the degree of temperature and water stress is the photosynthetic apparatus in plants where climate tolerance can be recorded via measurements of photosynthesis parameters and chlorophyll fluorescence.

Among these approaches, chlorophyll fluorescence is a fast, non-destructive and effective technique to detect damage to the Photosystem II (PSII) in plants, when they are exposed to abiotic stress (Baker and Rosenqvist, 2004). The measurement of parameters that determine photosynthetic efficiency is based on chlorophyll fluorescence. When chlorophyll absorbs light, the electrons in the reaction centers of the photosystems are excited and raised to a higher energetic level. If this energy is not used for photochemistry or dissipated as heat, it is emitted as light, which is known as chlorophyll fluorescence. Changes in chlorophyll fluorescence indicate alterations in photosynthetic efficiency or indeed stress responses.

In particular, the activity of PSII is relevant. The effective quantum yield of PSII measures how efficiently the plant uses absorbed light for photosynthesis in PSII under light conditions. When chlorophyll fluorescence increases, the efficiency of PSII typically decreases, because more of the absorbed light energy is being lost as fluorescence rather than being used for photochemistry. Climate change stresses the photosynthetic apparatus in particular, leading to less efficient electron transport. The maximum quantum efficiency of PSII (F_v/F_m) is one of the most important chlorophyll fluorescence parameters (Baker, 2008). In previous research, F_v/F_m has been successfully applied for distinguishing the susceptibility of wheat (Sharma et al., 2012) and tomato (Zhou et al., 2015) under high temperatures. Similarly, the susceptibility of soybean, tomato and maize to stresses has been identified using F_v/F_m in literally all stages of development of the crop.

On one hand, a screening system of breeding populations would be appropriate when the selection criteria are simple, and the method provides an accurate and rapid evaluation of the response of the plants to the environment. On the other hand, the heterogeneity and

variability of the environment is challenging if the screening is conducted in the field (Stoddard et al., 2006), but in many cases it has been possible to develop methods in controlled environments that could be transferred to field (Poudyal et al., 2019)

The aims of the present report and the database are to give an overview of the stress effects of some of the key legume species and how to perform selection linked to the possibilities of accessing germplasm of different origins and accessible gene bank depositories.

2. Stress in legumes

2.1 Effects of inadequate heat stress on legume physiology

Heat stress often disrupts membrane stability, increasing fluidity and permeability—a foundational problem that cascades into broader dysfunction. This results in electrolyte leakage, as observed in soybean, chickpea, faba bean, and lentil—indicators of thermotolerance variation across species (Sita et al., 2017), Photosynthetic machinery, particularly Photosystem II (PSII), is as mentioned a highly heat-sensitive. Damage to the thylakoid membranes, chlorophyll pigments, and key enzymes like RuBisCO activase reduces photosynthetic efficiency in legumes such as chickpea and soybean, diminishing carbohydrate formation and transport to reproductive tissues (Adireddy et al., 2024) as also seen in lupins (Kňazovický, 2025). Elevated temperatures spur ROS accumulation—as in soybean leaves under 38/28 °C conditions, where superoxide and hydrogen peroxide surged by over 60–70%, while antioxidant enzymes (SOD, CAT, POD) declined markedly (Liu et al., 2019). To counteract oxidative damage, legumes enhance antioxidant systems, including glutathione, ascorbate, proline, and osmolytes like glycine betaine—strategies demonstrated in mung bean, chickpea, and cowpea (Liu et al., 2019).

Legumes are particularly vulnerable during flowering and seed-filling. Heat stress at this stage disrupts stigma receptivity, ovule viability, pollen germination, and developmental processes such as tapetum integrity, often leading to flower and pod abortion and sharp yield declines—even with brief exposure above 35 °C (Liu et al., 2019, Dave et al., 2024) .

Legumes produce Heat Shock Proteins (HSPs) similar to other plant species under temperature stress to stabilize and refold denatured proteins. HSPs broadly contribute to enhanced physiological resilience, photosynthesis preservation, and membrane stability (Liu et al., 2019).

2.2. Effects of inadequate water supply on legume physiology

Drought is a significant abiotic stress that impairs various physiological processes in legumes (Khatun et al., 2021). The immediate effect of drought is reduced water uptake, leading to decreased turgor pressure and stomatal closure. This closure limits gas exchange, reducing photosynthesis and transpiration, which can ultimately reduce the growth rate and yield, but

in general drought stresses have a negative effect on the N-fixing Rhizobium systems (Zahran, 1999).

In peas, faba beans, and chickpeas, drought stress affects water-use efficiency by limiting the availability of soil moisture, thus reducing photosynthetic rates. Additionally, drought can increase the production of reactive oxygen species (ROS), leading to oxidative damage to cellular structures, including membranes, proteins, and DNA. Antioxidant enzyme activities (such as superoxide dismutase and catalase) tend to increase in response, though not always sufficiently to prevent damage.

Understanding plant–water relations is fundamental to explain water transport within plants under drought stress. Plant-available water is crucial for essential mechanisms such as transpiration, photosynthesis, and metabolic processes. Soil water is taken up by roots and moved upward through the xylem via the cohesion–tension mechanism driven by transpiration pull (Lucas et al., 2013). Water transport in the xylem vessels is also regulated through modulations in hydraulic conductance (Scharwies and Dinneny, 2019). During water stress the hydraulic conductance can be adjusted by altering stomatal conductance (Sperry et al., 2002).

2.3. Drought-tolerance

Varieties with drought might exhibit a more regulated expression pattern, with a baseline activation of protective genes (like antioxidant enzymes) even under non-stress conditions. Varieties from arid regions may possess enhanced expression of genes involved in osmotic adjustment (e.g., betaine aldehyde dehydrogenase) and stomatal regulation compared to those from temperate climates.

Varieties from arid regions may possess enhanced expression of genes involved in osmotic adjustment (e.g., betaine aldehyde dehydrogenase) and stomatal regulation compared to those from temperate climates, often it might be associated with more extensive root growth typically laterally. Specific gene clusters related to water-use efficiency and root development are often more actively expressed in drought-tolerant varieties, facilitating better water uptake.

Drought reduces plant growth due to decreased cell division and expansion. In peas, the reduction in shoot and root biomass is significant under severe water deficit, affecting overall plant size and development. Similarly, faba beans and chickpeas exhibit reduced stem elongation and leaf area, leading to lower photosynthetic capacity.

Yield reduction is one of the most critical consequences of drought stress. Water shortage during the flowering and pod-filling stages leads to reduced pod formation, smaller seed size, and lower seed number. For example, chickpeas experience yield losses of up to 40-50% under severe drought conditions.

Germination can be critical for establishing drought resilience. Drought-sensitive varieties may show slower germination rates under low water availability, while tolerant varieties activate stress response pathways more rapidly (Nadeem et al., 2019a).

During the *vegetative stage*, drought stress often leads to reduced leaf expansion and root growth. Tolerant varieties might exhibit enhanced root development and deeper rooting patterns, supported by differential gene expression (auxin and cytokinin-related genes). Drought stress during *flowering and pod setting* can severely impact yield (Mwanamwenge, 1999). Tolerant varieties often have better reproductive success due to effective stomatal regulation and higher metabolic activity related to nutrient allocation.

2.4. Salinity Stress

Salinity stress occurs when high levels of salts in the soil impede the plant's ability to take up water. In legumes, high salinity leads to osmotic stress and ion toxicity, primarily due to excess sodium (Na^+) and chloride (Cl^-) ions. These ions disrupt cellular ion homeostasis, affecting enzymatic activities and leading to nutrient imbalances (Chaudhary et al., 2024).

Salinity also reduces the plant's water uptake efficiency, mimicking drought-like conditions. In faba beans and chickpeas, salinity can lead to increased abscisic acid (ABA) levels, promoting stomatal closure and reducing photosynthesis. Prolonged exposure can cause leaf chlorosis, necrosis, and eventual plant death (Nadeem et al., 2019b)

Growth inhibition under salinity is characterized by stunted shoot growth and reduced leaf area, leading to poor plant development. The uptake of toxic ions (Na^+ and Cl^-) disrupts the plant's nutrient balance, particularly in terms of potassium (K^+) and calcium (Ca^{2+}), which are essential for growth and development (Mi et al., 2023).

In peas and faba beans, high salinity levels reduce pod number, seed weight, and yield. Chickpeas also suffer from reduced pod set and smaller seeds due to salinity. The osmotic stress imposed by salinity reduces water uptake, further aggravating the yield loss.

2.5. Waterlogging Stress

Flooding results in an anaerobic soil environment that severely restricts oxygen availability to roots, impairing respiration. Legumes, particularly peas and faba beans, are highly susceptible to waterlogging. This condition causes a significant reduction in root oxygen, leading to root hypoxia or anoxia, causing a decline in nutrient uptake and energy production (Manghwar et al., 2024).

Waterlogging increases ethylene production, inducing premature senescence and root decay. In chickpeas, waterlogging is associated with chlorophyll degradation and reduced leaf photosynthetic efficiency (Cowie et al., 1996). Waterlogging adversely affects root growth, leading

to poor nutrient uptake, which stunts above-ground growth. In peas and faba beans, waterlogged conditions during critical growth stages such as flowering or pod filling cause reduced pod numbers and seed development, leading to lower yields.

Chickpeas are particularly sensitive to waterlogging, with significant reductions in root biomass, leading to poor nutrient acquisition and decreased yield. Yield losses can reach up to 50% in some cases under prolonged waterlogged conditions.

3. Effects on Seed Quality

3.1. Proteins

Water stress alters the protein content in legumes. Drought tends to reduce the total protein content in seeds of peas, faba beans, and chickpeas. This is primarily due to the reduced nitrogen uptake and translocation during stress conditions. Under salinity, protein synthesis is often impaired due to ion toxicity and energy limitations. In contrast, waterlogging can lead to either a decrease or no change in seed protein levels, depending on the duration and severity of the stress.

3.2. Carbohydrates

Carbohydrate metabolism is highly sensitive to water stress. Under drought conditions, carbohydrate accumulation in seeds can decrease due to impaired photosynthesis. Salinity stress reduces starch content in seeds as the metabolic balance shifts towards the production of osmolytes (such as proline and sugars) for osmotic adjustment. Waterlogging, by reducing photosynthetic efficiency, also negatively impacts carbohydrate accumulation.

3.3. Nutrients

Water stress affects the nutrient profile of legume seeds. Drought reduces the uptake of key nutrients such as nitrogen (N), phosphorus (P), and potassium (K), which are crucial for seed development and quality. Salinity stress exacerbates nutrient imbalances by competing with essential nutrients (e.g., Na^+ replacing K^+). Waterlogged soils, due to poor aeration, reduce the uptake of minerals like iron (Fe) and zinc (Zn), resulting in nutrient-deficient seeds.

3.4. Antinutritional Factors

Antinutritional factors, such as tannins, phytic acid, and protease inhibitors, are influenced by water stress. Drought has been shown to increase the concentration of antinutritional compounds in legumes, possibly as a stress-response mechanism. Salinity also leads to higher levels of antinutritional factors, which affect protein digestibility and nutrient bioavailability. However, waterlogging tends to have variable effects, with some studies showing increases while others report decreases in these compounds.

3.5. Minerals

Water stress alters the mineral composition of seeds. Drought reduces the concentration of minerals such as calcium (Ca), magnesium (Mg), and potassium (K) in legumes. Salinity stress can cause an accumulation of sodium (Na) and chloride (Cl) in seeds while decreasing the levels of beneficial minerals like K, Mg, and calcium. Waterlogging disrupts the uptake of essential minerals like zinc (Zn) and iron (Fe), leading to deficiencies in seed mineral content.

4. The background for the database

This task will identify climate resilient varieties of protein crops by deploying existing, high throughput methodologies under controlled environment conditions. Pre-selected near-commercial and commercial varieties will be systematically evaluated to determine their suitability for specific European pedoclimatic regions through the operations of IPS 2 for validation and demonstration. The initial focus has been on **chickpea, pea, lupin, and faba bean**, chosen for their high agronomic and market potential. Further crop species identified may be included, pending the outputs of the gap analysis (T1.1) and seed availability. Pre-selection of candidate varieties will be carried out in consultation with breeders and national variety evaluation offices, ensuring that materials with superior agronomic performance are prioritized.

4.1. The database

A **searchable database** has been developed containing quantitative data on agronomic performance and primary composition across European countries. This database is dynamic and will be added to in the remainder of the project. The database will serve as a practical decision-support tool, enabling breeders, farmers, and other stakeholders to match legume varieties to potential value chains (based on nutritional profiling) and pedoclimatic conditions. To complement the agronomic and compositional performance data of chickpea, pea, lupin, and soybean across European countries, additional datasets were generated to capture the responses of legumes to abiotic stresses under contrasting environmental conditions. Across partner sites in Italy, Germany, and Denmark, a range of commercial and pre-commercial varieties were evaluated under controlled and field conditions characterized by varying temperature and precipitation regimes.

In Italy, pea and chickpea genotypes were tested across four growing seasons with contrasting meteorological trends, providing insights into varietal stability under fluctuating climatic conditions.

In Germany, chickpea varieties were evaluated in multi-environment trials, revealing strong genotype × environment interactions: while ‘Cicerone’ displayed high yield stability, varieties such as ‘Orion’ and ‘Irenka’ were better adapted to distinct environments. Drought stress trials

using rainout shelters further demonstrated species- and stage-specific sensitivities, with chickpea highly vulnerable at flowering, soybean and yellow lupin at pod filling, while white lupin and winter pea showed resilience.

In Denmark, physiological analyses of lupins under heat stress highlighted grain filling as a critical stage, with varieties such as 'Mirabor', 'Iris', and 'Jenabillup' maintaining photosynthetic function and yield stability, whereas 'Primabella' and 'Primadonna' suffered significant declines.

These datasets, now integrated into the searchable database, provide a harmonized resource that links phenotypic trait responses to abiotic stress factors across multiple species, environments, and European pedoclimatic zones. The combined outputs strengthen the database as a decision-support tool for breeders, farmers, and policymakers, enabling region-specific recommendations and guiding the selection of more resilient protein crops in alignment with Farm to Fork 2030 goals.

4.2. Gene banks

Genebanks play a critical role in conserving the genetic diversity of faba bean (*Vicia faba*), also known as broad bean. These facilities store germplasm (seeds, tissue, or other genetic material) for research, breeding, and conservation purposes, helping to safeguard agricultural biodiversity and resilience.

4.2.1. Key Genebanks for Faba Bean Germplasm

Several major genebanks worldwide are known for holding large collections of faba bean germplasm. Here's an overview of the primary repositories:

International Center for Agricultural Research in the Dry Areas (ICARDA)

- **Location:** Morocco (previously Syria, with backups in Lebanon and Turkey)
- **Collection:** ICARDA holds one of the largest collections of faba bean germplasm, with approximately 8,000 accessions.
- **Focus:** This collection emphasizes landraces, wild relatives, and improved varieties. ICARDA's focus on dryland agriculture makes it an essential resource for faba beans, particularly for drought tolerance and pest resistance traits.

4.2.2. European Gene banks (ECPGR)

The European Cooperative Programme for Plant Genetic Resources (ECPGR) coordinates several national genebanks across Europe.

- **Collection:** Collectively, European genebanks hold around 12,000 accessions of faba bean. Countries like Germany, Spain, and Italy have substantial collections.

- **Notable Genebanks:**
- **Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Germany**
- **Spanish National Research Council (CSIC), Spain**
- European collections tend to focus on local landraces, cultivated varieties, and genetic diversity for breeding programs.

4.2.3. Australian Grains Genebank (AGG)

- **Location:** Australia.
- **Collection:** Approximately 1,000 faba bean accessions.
- **Focus:** The AGG collection supports breeding programs that focus on disease resistance (e.g., chocolate spot, rust) and adaptation to Australian growing conditions.

4.2.4. United States Department of Agriculture (USDA) National Plant Germplasm System (NPGS)

- **Location:** Primarily based in Pullman, Washington.
- **Collection:** Around 800 accessions.
- **Focus:** The USDA collection supports research and breeding with a focus on traits relevant to North American growing conditions, including disease resistance and adaptability to cooler climates.

4.2.5. China, India, and Egypt

have significant faba bean germplasm collections, with thousands of accessions combined. These genebanks support local breeding programs, focusing on traits such as drought tolerance, disease resistance, and yield stability under regional conditions.

4.2.6. Global Estimate of Faba Bean Accessions

The total global collection of faba bean germplasm across all genebanks is estimated to be around **25,000 accessions**. This diversity includes wild relatives, landraces, and improved cultivars, representing a broad genetic base for breeding programs.

4.2.7. Importance of Faba Bean Germplasm

Faba bean genebank collections are critical for: **Breeding** for pest and disease resistance, **Improving** climate resilience and adaptability to different environmental conditions, **Maintaining genetic diversity** to counter potential challenges from climate change, pests, and diseases.

These resources are essential for the long-term sustainability and resilience of faba bean crops globally.

4.2.8. Key Global Gene banks for Chickpea

- **International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)**
Located in Hyderabad, India, ICRISAT holds one of the largest collections of chickpea germplasm. Its collection includes around 20,000 chickpea accessions representing global diversity, including cultivated species (*Cicer arietinum*) and wild relatives.
- **United States Department of Agriculture (USDA) Genebank.** The USDA's National Plant Germplasm System holds chickpea germplasm primarily from North America, with around 5,000 chickpea accessions. These accessions cover a variety of traits significant to U.S. agriculture and chickpea breeding programs.
- **Australian Grains Genebank (AGG)** that holds a sizable chickpea collection and focuses on traits critical to Australian agricultural conditions, such as drought tolerance. Their collection comprises several thousand accessions, including local and international varieties.
- **International Center for Agricultural Research in the Dry Areas (ICARDA)**
Located in Morocco, ICARDA holds over 10,000 chickpea accessions, including both *Cicer arietinum* and its wild relatives. This collection is highly valuable for research on drought resilience and pest resistance, as ICARDA focuses on dryland agriculture.
- **Indian National Bureau of Plant Genetic Resources (NBPGR)**
is part of the Indian Council of Agricultural Research (ICAR), conserves chickpea varieties domestically significant to India. This collection includes about 15,000 chickpea accessions, focusing on India's diverse agroecological zones.

4.2.9. Total Chickpea Germplasm Collection

In total, over **40,000 chickpea accessions** are conserved across various genebanks worldwide. This germplasm is essential for breeding programs that aim to improve chickpea resilience, yield, and adaptability under changing climate conditions. If you're interested in specific chickpea traits or genebank accessions, some genebanks provide online databases where accessions can be browsed by traits, origin, and other characteristics.

5. Future legume crops

Selecting future legume crops for the European market involves identifying varieties that suit specific environmental conditions, consumer preferences, and agronomic needs. Legumes are highly valued for their protein content, nitrogen-fixing abilities, and adaptability to sustainable agricultural practices. But much effort is still needed and here's a possible outline/roadmap for

turning those scattered, under-documented cool-season legume accessions into climate-proofed crops.:

Broaden and Streamline Germplasm Access

- Forge partnerships with regional genebanks (e.g. ICARDA, CGIAR) and university collections—pool requests to meet minimum-order sizes.
- Tap into breeder networks and farmer cooperatives for “on-farm” landraces and wild relatives that often sit outside formal collections.
- Investigate cryo- or in-vitro storage platforms to bank small amounts of seed/tissue and speed-up regeneration cycles without full field multiplication..

Rapid Multiplication via Speed Breeding & Doubled Haploids

- Speed breeding to grow successive generations under extended-photoperiod growth chambers (22 h light, 2 h dark), which would cut generation time to 6–8 weeks or include stress to speed up flowering

Multi-Stress Phenotyping and potential capacity analysis

- Simultaneous heat + drought chambers with real-time soil moisture probes, canopy temperature sensors and leaf gas-exchange analyzers.
- Time-series sampling for: Key physiologies (stomatal conductance, chlorophyll fluorescence, root depth) and biochemical markers (proline/osmolytes, antioxidant enzyme activity)
- Long-term follow-up to capture yield-component responses.
- Explore epigenetic priming: mild pre-stress treatments that can confer transgenerational tolerance.
- Selection based on legumes' ability to fix nitrogen, reducing synthetic fertilizer needs and promoting crop rotation and soil health

Deep Genotyping and Omics Integration

- Targeted resequencing of stress-linked candidate genes (heat-shock proteins, dehydrins, aquaporins).
- Transcriptome and metabolome profiling under single vs. combined stress to pinpoint interaction networks that only emerge under dual stress.

Association Mapping & Genomic Prediction

- Run Genome-Wide Association Studies (GWAS) across specific varietal panels under each stress regime—identify stable QTLs vs. stress-specific loci.
- Build Genomic Selection (GS) models that predict performance under heat + drought, accelerating selection without multiple field cycles.

Pre-Breeding and Precision Crossing

- Select top-performing donor lines (from your GS predictions) and cross into elite, locally adapted backgrounds.
- Use marker-assisted backcrossing or CRISPR-guided edits to stack favorable alleles for both heat and drought tolerance.

Field Validation and Participatory Trials

- Test advanced lines across contrasting cool-season environments (northern Europe vs. Mediterranean highlands).
- Engage farmers in on-farm strips to capture traits like harvest index and disease resilience under real-world conditions.

6. Conclusion

Water stress, including drought, salinity, and waterlogging, severely impacts the physiological processes, growth, and yield of legumes such as peas, faba beans, and chickpeas. Each stressor impairs plant performance through various mechanisms, leading to reduced yield and altered seed quality. Proteins, carbohydrates, nutrients, antinutritional factors, and mineral contents are all affected, with significant implications for the nutritional value of the beans. Developing water stress-tolerant legume varieties and adopting water management strategies are critical to ensuring sustainable production and maintaining seed quality under adverse environmental conditions.

Overall, the interaction between drought stress, gene expression, and metabolite composition varies significantly among faba bean varieties from different geographical regions. Drought-tolerant varieties demonstrate more adaptive strategies at the genetic and metabolic levels, enhancing their ability to survive and maintain productivity under water-limited conditions. Understanding these differences is crucial for breeding programs aimed at developing resilient faba bean varieties in the face of climate change.

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9. Appendix: Guide for Using the VALPRO Path Variety Database

1. Purpose of the Database

This database compiles agronomic and primary composition data of legume varieties (e.g., chickpea, pea, lupin, faba bean, etc.) collected across multiple European sites. It serves as a decision-support tool for breeders, farmers, advisors, and researchers to:

- Compare the performance of varieties under different pedoclimatic conditions.
- Identify climate-resilient and high-performing varieties.
- Link varieties to value chains (food, feed, processing).

2. Structure of the File

The Excel workbook contains one sheet per crop species (e.g., Chickpea, Field Pea, Lupin, Faba Bean, etc.).

Each sheet is divided into two main data sections:

1. Agronomic Data– includes site, year, replication, flowering/harvest date, yield, plant height, soil type, irrigation regime, etc.

2. Primary Analytical Data– includes seed protein, lipid, carbohydrate, ash, moisture, etc.

Additional metadata such as GPS location, field contact, climate description are also included.

3. How to Navigate & Search

- Use the bottom tabs to switch between crop species.
- Use the Filter tool (Excel/Data → Filter) to sort or search by:
 - o Country (e.g., Germany, Italy)
 - o Variety name
 - o Harvest year
 - o Agronomic traits (e.g., plant height, yield, irrigation regime)
 - o Nutritional traits (e.g., protein %, lipid content).

4. Interpretation of Data

- Agronomic data: allows comparison of variety performance under specific environments (e.g., rain-fed vs. irrigated).
- Nutritional data: supports identification of varieties with superior composition for food/feed use.
- Replications: replicate rows show different field repetitions for the same variety.
- Notes column: indicates specific classification (e.g., desi vs. Kabuli type).

5. Practical Examples

- Breeders: filter by "Variety name" and compare across years/locations for stability.
- Farmers: filter by "Country" + "Soil type" + "Yield" to identify best-fit varieties for local conditions.
- Value-chain actors: filter by "Protein content" or "Carbohydrate content" to match processing needs.