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22. Plant Ideotype and Climate Resilient Crop

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Abstract:

This analysis explores the progress in breeding and genetic engineering for developing climate-resilient crops. It examines the Ideotype breeding approach for enhanced selection efficiency, addressing abiotic stress tolerance to withstand adverse conditions like drought, heat, and salinity, and biotic stress management for resistance against pests, diseases, and weeds. Additionally, it highlights the significance of improving nutritional value through biofortification and minimizing antinutritional elements. The future prospects involve integrating multiple traits, using extensive data, considering socioeconomic aspects, and establishing a strong regulatory framework.

The research underscores the importance of collaborative efforts among various stakeholders to promote the adoption of climate-resilient crops, crucial for food security and sustainable agriculture.

Keywords:

Climate-Resilient Crops, Ideotype Breeding Approach, Abiotic Stress Tolerance, Biotic Stress Management, Biofortification and Agricultural Sustainability

22.1 Introduction:

Climate change, threatening global agricultural productivity and food security, necessitates developing climate-resilient crops through the Plant Ideotype-based approach, introduced by Donald in 1968. This method focuses on breeding crops with traits resilient to stressors like extreme temperatures, drought, salinity, flooding, and pests, optimizing plants for specific environmental conditions. ombining traditional, molecular, genomic, and transgenic breeding methods, scientists aim to enhance tolerance to abiotic stressors and manage biotic stressors, as highlighted by researchers like Lobell, D. et al. 2011 and Savary, S. et al.2012.The goal is to produce crop varieties resilient to these challenges while maintaining yield and nutritional quality, a crucial step in ensuring stable food production amid adverse climatic conditions.

22.2 Defining an Ideotype: What and What For?

In 1968, Donald defined an ideotype as a "biological model which is expected to perform or behave in a predictable manner within a defined environment". This plant model contains physiological and morphological features that improve plant performance in the target environment. Ideotype breeding was his third intriguing selection method. Rice may be the most successful ideotype breeding crop. Peng et al. (2008) found that ideotype selection yielded 8–15% more than classical selection. The ideotype was a plant with modest tillering, heavy and dropping panicles, some morphological features of the top three leaves, and a panicle-optimal position.

Identifying the traits and mechanisms affecting the various breeding goals and integrating them in a single model allows one to disentangle the correlation (negative or positive) between those goals and identify combinations of traits, sometimes poorly related, that provide an acceptable trade-off. The genotype ideotype distance index, introduced by Cruz (2006), is useful in multi-criteria selection (Teixeira et al., 2017). Researchers have found features of possible interest under specific farming settings using plant and crop models and rapidly improving computational capability.

22.3 A Method to Design Ideotypes:

The method described below results from a collective discussion developed during a research school and a seminar1 in France on ideotype topic. It has been precisely described in Debaeke and Quilot-Turion (2014) and in Debaeke et al. (2014). It consists in

a. defining the specifications of the varieties
b. designing and building the ideotypes and
c. assessing their ability to meet the specifications

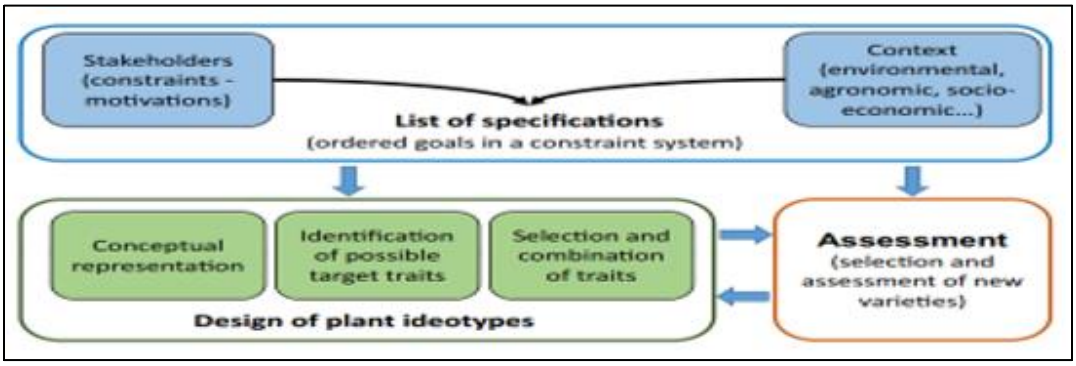

Figure 22.1: The main steps of an ideotyping process (Source: G Arnaud 2018)

A. The Definition of The Varietal Specifications:

In crop breeding, the Target Population of Environments (TPE) approach customizes breeding goals by identifying environments with similar stress patterns for optimal growth (Finckh et al., 2000).

This method, integrating stakeholder perspectives and advanced crop models, adapts to future climate changes and varying agricultural practices. It enables precise farm classification and cultivar recommendations, optimizing crop production and efficiency in each unique environmental setting.

B. The Design of New Ideotypes:

Breeding evolves through ideotype breeding, a process where a conceptual plant model, often diverging from existing varieties, guides trait selection (Prost et al., 2018; Berthet et al.,2015). This innovative approach, integrating genetics, agronomy, and farming insights, uses computer models and optimization algorithms to identify key traits for specific agricultural contexts. It enhances variety selection, meeting challenges of changing farming conditions and diverse consumer demands, exemplified by Donald's 1968 wheat model.

C. The Assessment of Ideotypes:

Ideotype evaluation in plant breeding involves selecting variations that match the defined model, using measurable qualities and genetic markers. High throughput phenotyping characterizes traits and identifies quantitative trait loci (QTL). Evaluation requires trials in varied environments, analyzing how genotypes interact with factors like water, temperature, and CO2. Traditional Genotype x Environment analysis, now including multiple variables like yield and disease resistance, is enhanced by multi-criteria analysis for optimal variety refinement.

22.4 Ideotype of Some Selected Crops:

Rice:

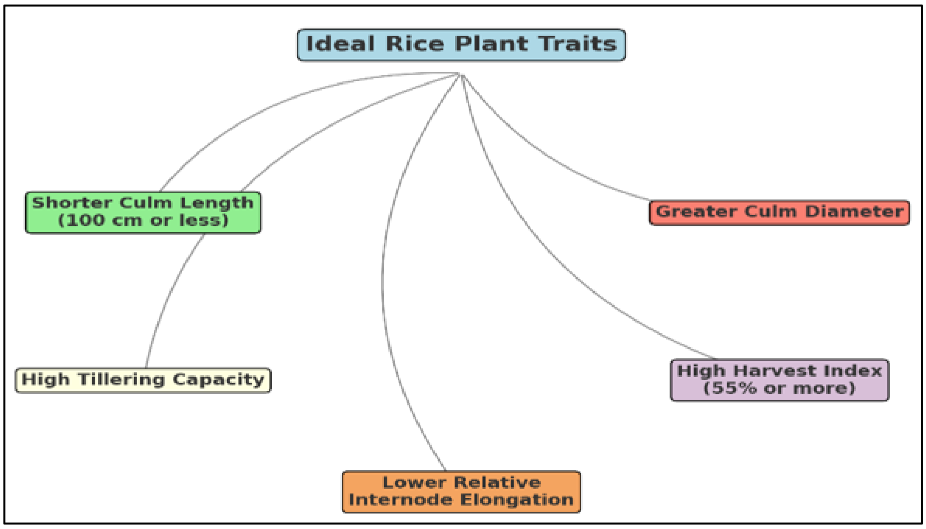

Figure 22.2: Rice

New Plant Ideotype:

- Consider the effect of changing climate and nature of biotic and abiotic stress.
- NPI (Japonica Rice): Peng *et al*. (1993), IRRI developed Ist generation NPI
- Low tillering with 3-4 panicle/plant under direct seeding
- No unproductive tillers
- Sturdy stem, thick and erect leaves
- 200-250 grains/panicle
- Plant height: 90-100 cm, vigorous root system
- Multiple IP&D resistance
- Duration: 120-130 days; HI= 0.6 or 60 %
- Yield potential: 13-15 t/ha
- Grain yield was not high as expected due to poor biomass production & poor grain filling which led to II generation NPI

Peng & G S Khush (2003) developed IIst generation NPI (Ist generation × Indica)

- 330 panicle/m^{-2}, 150 spikelets/ panicle
- Grain filling: 80 %; Grain wt.: 25 mg/grain
- Total biomass above ground: 22 t/ha
- Grain yield: 11 t/ha
- HI: 50 %

Wheat:

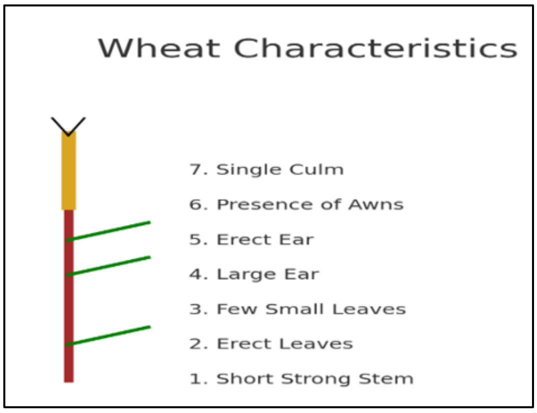

Figure 22.3: Wheat

Maize:

- Stiff-vertically-oriented leaves above the ear
- Maximum photosynthetic efficiency
- Efficient translocation of photosynthate into grain
- Small tassel size
- Cold tolerance of germinating seeds and developing seedlings

Barley:

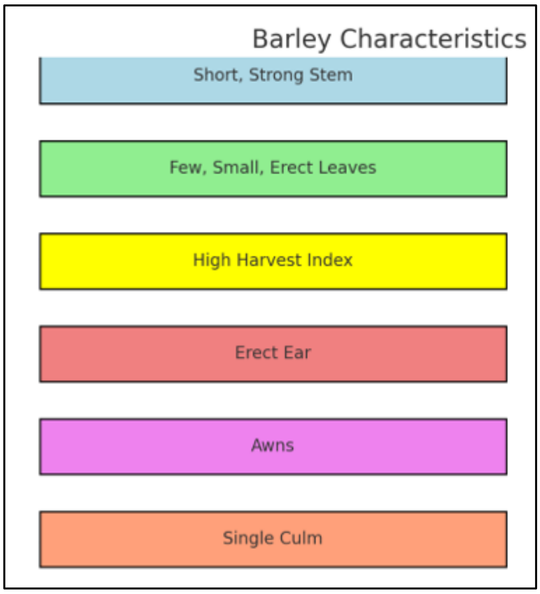

Figure 22.4: Barley Characteristics

General Plant Ideotype Concept in Pulses

- Erect and upright plant
- Average plant height
- Early vigour, early flowering and synchronous maturity
- Pod bearing from well above the soil surface
- More pods/plant and a greater number of seeds /pods
- High harvest index
- Yield stability

Chickpea Rainfed Condition:

- Early vigour
- 50-60 cm plant height with 9-10 secondary branches
- Tall, erect or semi-erect plant
- More number of pods per plant
- Podding from 10th node

Irrigated Condition:

- High input responsiveness
- Tall (75-90 cm) and erect habit with broom shaped branching behaviour
- Synchronous flowering, delayed senescence and determinacy
- Long fruiting branches and short inter nodes
- Lodging resistance
- Pod bearing from 20 cm above the ground

Brassica Species:

- Plant ht. 1-1.25 m
- 5-6 primary branches at 40-45 ° angle
- Deep root system
- 20 seeds/siliqua
- Low dark respiration rate
- High nitrate reductase activity
- Main stem should bear maximum siliquae (40)
- Lower three branches should have less siliquae (15)

Irrigated Cotton:

- Plants of short stature (90-120 cm)
- Compact and sympodial plant habit
- Short duration
- Responsive to high fertilizer dose.
- High degree of resistance to insect pests and diseases.

- boll size in proposed to be between 3.5 and 4 g.

Rainfed cotton

- Few smaller and thick leaves with sparse hairiness
- Medium to big boll size (3.5 to 4 g)
- Responsive to nutrients
- High degree of resistance to insects and diseases
- Synchronous bolling habit
- Short stature (75-80 cm) and compact plant habit

22.5 Merits of Ideotype breeding:

- Ideotype breeding enhances crop yield by leveraging morphological and physiological trait variations.
- This method specifies a variety of morphological and physiological characteristics, each contributing to improved yield.
- It requires multidisciplinary collaboration among experts in plant breeding, physiology, biochemistry, entomology, plant pathology, and biotechnology to develop model plants with field-specific traits.
- Ideotype breeding effectively breaks yield barriers by utilizing genetically controlled physiological variations across multiple traits.
- It addresses several challenges concurrently, such as disease, pest, and lodging resistance, maturation time, yield, and quality, by combining favorable genes into a single genotype.
- The approach is tailored to develop cultivars that are well-suited to specific environments.

22.6 Demerits of Ideotype Breeding:

- Combining favourable physical, biological, and resistance traits into a single genotype is complex due to linkages between desired and undesired traits.
- Ideotype breeding, which integrates multiple traits, is more time-intensive compared to traditional yield-focused breeding.
- Ideotype breeding complements, rather than replaces, traditional breeding methods.
- Ideotypes are adaptable, evolving with advances in knowledge and changing economic and policy demands.

Why Not Selecting an Ideotype?

Despite the potential effectiveness of an ideotype-based approach, it's crucial to consider relevant criticisms.

- Ideotype design involves gathering knowledge from various scientific fields, with a focus on filling knowledge gaps, especially for lesser-studied orphan crops.

- Insights for ideotype development can be derived from related species and integrated with non-scientific knowledge in expert-based models.
- This approach requires multidisciplinary expertise and is complemented by genetic methods like genomic selection Heslot et al., 2014; Ly et al., 2018).
- While ideotype-based breeding aims for specific trait efficiency, it risks creating non-optimal ideotypes, particularly when multiple breeding goals are involved.
- The sequential approach to breeding goals, due to specialized knowledge, can result in non-optimal initial ideotypes in certain areas like disease resistance.

The concept of a plant ideotype, rooted in agricultural research, is key to developing climate-resilient crops. Ideotypes are idealized plant structures designed to maximize crop yield in specific environmental conditions. Faced with climate change-induced unpredictable weather and harsh conditions, breeding crops with resilient ideotypes is vital. By focusing on traits like drought tolerance, heat resistance, and efficient resource utilization, researchers aim to enhance crop adaptability to climate changes. This integration of ideotype and climate resilience equips agriculture to withstand climatic uncertainties, ensuring sustainable food production amidst climatic challenges.

What is Climate Resilience?

Walker et al. (2004) defines resilience as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks." Denton et al. (2014) explained that "A climate resilient pathway for development is a continuing process for managing changes in the climate and other driving forces affecting development, combining flexibility, innovativeness, and participative problem solving with effectiveness in mitigating and adapting to climate change.

What Is Climate Resilient Crop?

Climate-resilient crops and crop varieties were adopted to cope with abiotic stresses such as drought, heat, flooding, salinity and shorter growing season (early-maturing crops), as well as pests associated with changes in weather or climate patterns (disease and pest resistance).

Why We Need Climate Resilient Crops?

Climate-resilient crops are crucial in the face of climate change due to several scientific reasons:

- **Temperature Variability:** Climate-resilient crops are bred to withstand temperature fluctuations, ensuring optimal growth even in changing climates.
- **Adaptation to Extreme Events:** These crops are designed to endure extreme weather events such as floods, droughts, or storms, providing a stable food supply.
- **Changing Growing Seasons:** With climate-resilient traits, crops can adapt to shifts in growing seasons, maintaining productivity despite altered environmental conditions.

- **Mitigating Crop Diseases:** Resilient crops often possess traits that make them less susceptible to diseases and pests, reducing the need for chemical interventions.
- **Sustainable Agriculture:** By employing scientific methods, researchers can create crops with improved water-use efficiency, reducing the impact of agriculture on water resources.

Different Strategies for Development of Climate Resilient Crops:

Latest advancements in these strategies, focusing on the development of climate-resilient crops through conventional breeding techniques, molecular breeding methods, genomic and transgenic approaches, as well as their application in improving abiotic stress tolerance and managing biotic stresses.

Table 22.1: Examples of Breeding Approaches for Abiotic Stress Tolerance:

Crop	Abiotic Stress	Breeding Approach
Rice	Drought	Marker-assisted selection for drought QTLs
Maize	Heat	Introgression of heat-tolerant genes
Wheat	Cold	Selection for vernalization genes
Soyabean	Salinity	Identification of salt-tolerant germplasm
Barley	Flood	Screening for submergence tolerance traits

(Source: Hafeez, U *et al*., (2023)

Conventional Breeding Techniques:

- **Selection:** Identifies and cultivates plants with exceptional traits (e.g., drought resistance, disease Figurehting) in specific habitats, enhancing stress tolerance over generations.
- **Hybridization:** Crosses genetically diverse plants to combine beneficial traits, producing hybrids with improved resilience and performance (Dwivedi, S. et al, (2017), Zafar, S. et al 2020).
- **Mutation Breeding:** Uses radiation or chemicals to induce genetic changes, creating crops with new stress-resistant characteristics.

Molecular Breeding Techniques:

- **Molecular Markers:** Leverages plant genome knowledge to select for stress tolerance traits at the molecular level (Cobb, J.et al.2019: Lebedev, V.2020)
- **Marker-Assisted Selection (MAS):** Efficiently identifies and selects plants with desired stress tolerance traits using genetic markers.
- **Utilization of Genetic Resources:** Integrates genes from wild crop relatives and landraces into cultivated varieties to enhance genetic diversity and stress tolerance.

Genomic and Transgenic Approaches:

- **Genome-Wide Association Studies (GWAS) and QTL Mapping:** Identifies genome areas linked to stress tolerance, analyzing genetic markers in plant populations (Varshney, R. K.2019; Mohammadi, M.2020).
- **Genomic Selection:** Uses genomic data for plant selection, expediting the breeding process by reducing reliance on phenotypic assessment.
- **Genetic Engineering:** Inserts specific genes for traits like insect resistance (e.g., Bt toxins) and abiotic stress tolerance (e.g., drought, salinity).
- **CRISPR-Cas9 Genome Editing:** Precisely alters specific genes to enhance stress response, offering targeted mutation opportunities.

Overall Impact:

- These methods combine traditional and molecular breeding with advanced genomic and transgenic techniques.
- They improve crops' resilience to abiotic stresses like drought, heat, salinity, and biotic pressures like pests and diseases.
- The integration of these strategies is crucial for developing climate-resilient crop varieties, essential for sustainable food production in changing climates.

22.7 Enhancing Abiotic Stress Tolerance:

To ensure sustainable agriculture and food security, it's crucial to develop crops that can withstand abiotic stressors like drought, heat, cold, salt, and flooding. Breeding tactics and genetic mechanisms are being employed to enhance crop resilience and adaptation to these unfavorable environmental conditions, addressing the challenges posed by climate change.

Drought Tolerance in Crop Breeding:

- **Drought Impact:** Destructive abiotic stress significantly affecting global agricultural output.
- **Breeding for Drought Resistance:** Involves identifying and integrating traits enabling plants to maintain productivity under limited water availability.
- **Focus on Genetic and Physiological Mechanisms:** Understanding these mechanisms is key to developing drought-resistant crops.

Key Features for Drought Resistance:

- **Stomatal Regulation:** Essential for water balance; cultivars with fewer or more responsive stomata show enhanced drought resistance.
- **Root Architecture:** Deep and extensive root systems improve water retrieval from deeper soil layers.
- **Osmotic Adjustment:** Plants accumulate solutes to maintain cellular hydration and turgor during drought (Cattivelli, L. 2008).

Molecular Breeding Techniques:

- **Marker-Assisted Selection and Genomic Approaches:** Facilitate identification and utilization of genetic markers and genes linked to drought resistance.
- **Transcription Factors and Stress-Responsive Genes:** These have been identified and used in breeding programs to enhance drought tolerance.
- **Integration with High-Throughput Phenotyping:** Accelerates the development of drought-resilient crop varieties.

Breeding for Heat Tolerance:

- Focuses on integrating features for enduring high temperatures and sustaining growth.

Key characteristics include:

- **Heat Shock Proteins:** Act as molecular chaperones to protect proteins from heat-induced denaturation (Wang, W.2003)
- **Antioxidant Enzymes:** Such as superoxide dismutase and catalase, reduce oxidative damage from heat stress.
- **Photosynthesis-Related Features:** Including Rubisco activase, crucial for maintaining photosynthesis efficiency at high temperatures.

Breeding for Cold Tolerance:

- Centres on ensuring cellular membrane stability and osmotic balance management.

Important features include:

- **Cellular Membrane Stability:** Focus on lipid content alterations and substances that protect against freezing.
- **Osmotic Adjustment:** Similar to drought tolerance, it helps maintain cellular hydration and turgor during cold stress.
- Utilizes genomic techniques to identify genes and markers related to temperature responsiveness.

Breeding for Salinity Tolerance:

- Aims to develop crops that can withstand high salinity levels.

Key traits include:

- **Ion Regulation:** Maintaining a balanced level of ions while excluding harmful ones.
- **Osmotic Adjustment:** Preserving cellular hydration and turgor in saline conditions (Munns, R. et al 2008).
- **Antioxidant Defense:** Reducing oxidative stress from salt.

Breeding for Flood Tolerance:

- Focuses on enabling plants to thrive in oxygen-deprived environments.

Essential characteristics:

- **Development of Aerenchyma Tissue and Adventitious Roots:** For efficient oxygen transport to submerged roots.
- **Anaerobic Metabolic Pathways:** Like fermentation, for energy production in low oxygen conditions.
- Involves genomic research to uncover genes linked to ion balance, osmotic regulation, and submergence resilience.

22.8 Managing Biotic Stresses:

Biotic stresses such as pests, diseases, and weeds significantly affect crop productivity, often leading to major yield losses. Developing effective methods to manage these stressors is crucial for sustaining crop resilience and production. This discussion focuses on breeding strategies and genetic approaches aimed at enhancing the resistance of climate-resilient crops to these biotic challenges.

Disease Resistance:

- **Selective Breeding:** Effective for enhancing disease resistance in crops, reducing pathogen effects.
- **Vertical Resistance:** Offers high-level resistance or immunity against specific pathogen races, due to significant resistance genes (Jones, J. et al. 2006).
- **Horizontal Resistance:** Provides broad-spectrum, long-lasting resistance through accumulation of minor genes against various infections.
- **Breeding Techniques:** Include traditional breeding for incorporating resistant genes from wild species, and molecular techniques like marker-assisted selection for introducing resistance genes into cultivars.
- **Transgenic Methods:** Use of genes encoding pathogen-derived toxins or antifungal proteins to increase disease resistance.

Pest Resistance:

- **Goal:** To develop crop varieties with reduced vulnerability to pest infestations, minimizing financial losses.
- **Conventional Breeding:** Involves transferring pest resistance from wild relatives and landraces into cultivated crops (Smith, C. M. et al 2005).
- **Genetic Engineering:** Utilization of genes encoding insecticidal proteins (e.g., Bt toxins) for effective pest resistance.

Impact: Biotech crops with pest resistance have significantly reduced the need for chemical insecticides, benefiting both farmers and the environment.

Table 22.2: Examples of Pest Resistance Traits in Genetically Engineered Crops

Crop	Target pest	Transgene	Mode of Action
Cotton	Bollworm	Bt toxin	Insecticidal activity
Maize	Corn rootworm	RNAi technology	Interference with pest gene expression
Potato	Colorado potato beetle	Cry3A gene	Disrupts insect gut function
Soyabean	Soybean aphid	HvSTA1 gene	Inhibits insect feeding

(Source: Hafeez, U *et al*., 2023)

Weed Management:

- **Enhanced Weed Competitiveness and Herbicide Resistance:** Developing crop varieties with traits such as vigorous early growth, allelopathy (releasing chemicals that inhibit weeds), and tolerance to herbicides (Lowry, C. J.2018).
- **Support for Integrated Weed Management:** Breeding crops with specific growth patterns or phenology to complement cultural methods like intercropping and crop rotation, thereby reducing weed proliferation.
- **Breeding for Allelopathic Traits:** Selectively developing crops that naturally produce substances to suppress weed growth.
- **Utilizing Molecular Techniques:** Leveraging genomic approaches and gene editing technologies to identify and manipulate genes related to plant defense, thereby enhancing resistance against weeds, pests, and diseases.

22.9 Improving Nutritional Quality in Climate-Resilient Crops:

Biofortification as a Key Method:

- Enhancing vital nutrients (iron, zinc, provitamin A) in primary crops to address nutrient deficiencies in dependent populations.
- Focusing on genetic diversity and variability among crops for improved nutrient levels (Bouis, H. E., et al 2010).

Utilizing Genetic Resources:

- Assessing agricultural germplasm to find varieties with higher nutrient levels and traits for better nutrient absorption and storage.

Traditional and Molecular Breeding:

- Integrating nutritional improvements into high-quality crops using traditional breeding methods.

- Employing molecular breeding, including marker-assisted selection and genomics, for precise and effective biofortification.

Transgenic Approaches:

- Implementing transgenic methods to directly enhance crop nutritional composition, such as adding genes for provitamin A or iron and zinc transporters.

Antinutritional Factors:

Substances in crops that interfere with nutrient absorption or use in humans.

- **Common Examples:** Phytic acid in grains and legumes, tannins, oxalates, and enzymes that affect digestion.
- **Breeding Goals:** Reduce or eliminate these antinutritional factors to enhance crop nutritional value.
- **Strategies:**

    - Identify and select crop varieties with naturally lower levels of antinutritional substances.
    - Specifically target reduction of phytic acid to improve mineral availability.
    - Breed crops with lower levels of tannins, oxalates, and other digestion-affecting enzymes (Balaban, N. P. et al 2016)

- **Molecular Breeding Tools:** Utilize genomics and gene editing technologies to precisely manipulate genes responsible for antinutritional factors.
- **Outcome:** Creation of crop varieties with reduced antinutritional levels while maintaining other beneficial traits.

Table 22.3: Nutritional Profiles of Climate-Resilient Crop Varieties

Crop	**Essential Nutrient Content (per 100g)**	**Antinutritional Factors**
Maize	Iron: 2.7mg, Zinc: 2.1mg	Phytic acid: 620mg, Tannins: 150mg
Rice	Iron: 1.8mg, Zinc: 1.2mg	Phytic acid: 420mg, Lectins: Present
Wheat	Iron: 3.5mg, Zinc: 3.2mg	Gluten: Present
Beans	Iron: 6.0mg, Zinc: 2.8mg	Lectins: Present, Phytates: 200mg
Sweet Potato	Iron: 0.8mg, Zinc: 0.3mg	Oxalates: 8mg, Phytates: 120mg

(Source: Hafeez, U *et al*., 2023)

Enhancing Nutritional Quality Beyond Essential Nutrients:

- Focus not only on basic nutrients but also on amino acids, fatty acids, and vitamins Friedman, M. (1996).
- Selective breeding enhances protein content and amino acid profiles in crops.
- Improving fatty acid composition, like increasing omega-3 in soybeans, promotes better nutrition.
- Boosting vitamin content (e.g., Vitamin C, E) through selective breeding meets dietary needs.
- Molecular breeding and genomics help identify genes for key nutritional components.

22.10 Future Perspectives and Challenges:

The future of crop improvement hinges on integrating traits such as stress resistance and nutritional quality using both traditional and genetic engineering techniques, aided by advances in genomics. Harnessing big data and digital agriculture, including precision techniques, is crucial, though it faces challenges like data accessibility. Additionally, understanding farmers' socioeconomic needs and involving them in the breeding process is vital for successful crop adoption. Regulatory and biosafety compliance remains a key concern, requiring stakeholder engagement and focus on environmental impact.

22.11 Conclusion

The Ortiz-Bobea et al. (2021) study highlights a 21% decline in agricultural productivity due to climate change, but advancements in breeding technologies offer hope. These developments allow breeders to enhance genetic traits in climate-vulnerable regions, incorporating climate resilience and ideotype breeding for selection efficiency. Utilizing computing, data analysis, phenotyping, and genome analysis, these strategies significantly impact crop improvement. The potential for genetic progress in crops is promising, dependent on breeders and farmers adopting these technologies and governmental support through regulatory and financial mechanisms.

22.12 References:

1. Balaban, N. P., Suleimanova, A. D., Valeeva, L. R., Chastukhina, I. B., Rudakova, N. L., Sharipova, M. R., & Shakirov, E. V. (2016). Microbial phytases and phytate: exploring opportunities for sustainable phosphorus management in agriculture.
2. Berthet E, Barnaud C, Girard N, Labatut J, Martin G.(2015). How to foster agroecological innovations? A comparison of participatory design methods. J Environ Plan Manage 59(2): 280–301.
3. Bouis, H. E., & Welch, R. M. (2010). Biofortification—a sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. Crop science, 50, S-20.
4. Cattivelli, L., Rizza, F., Badeck, F. W., Mazzucotelli, E., Mastrangelo, A. M., Francia, E., ... & Stanca, A. M. (2008). Drought tolerance improvement in crop plants: an integrated view from breeding to genomics. Field crops research, 105(1-2), 1-14.

5. Cobb, J. N., DeClerck, G., Greenberg, A., Clark, R., McCouch, S., & Edwards, J. D. (2019). Next-generation phenotyping: Requirements and strategies for enhancing our understanding of genotype–phenotype relationships and its relevance to crop improvement. Theoretical and Applied Genetics, 132(3), 795-816.
6. Cruz, C. D. (2006). Programa GENES: biometria (No. 519.5). Universidad Federal de Vidcosa,.
7. Debaeke, P. P., & Quilot-Turion, B. (2014). Conception d'idéotypes de plantes pour une agriculture durable. In Ecole chercheur INRA (pp. 254-p). Forma Science.
8. Debaeke, P., Gauffreteau, A., Durel, C. E., & Jeuffroy, M. H. (2014). Conception d'idéotypes variétaux en réponse aux nouveaux con-textes agricoles et environnementaux.
9. Denton, F., Wilbanks, T. J., Abeysinghe, A. C., Burton, I., Gao, Q., Lemos, M. C., ... & Warner, K. (2014). Climate-resilient pathways: adaptation, mitigation, and sustainable development. Climate change, 1101-1131.
10. Dwivedi, S. L., Ceccarelli, S., Blair, M. W., Upadhyaya, H. D., Are, A. K., Ortiz, R., & Varshney, R. K. (2017). Landrace germplasm for improving yield and abiotic stress adaptation. Trends in Plant Science, 22(4), 337-348.
11. Finckh, M., Gacek, E., Goyeau, H., Lannou, C., Merz, U., Mundt, C., & Wolfe, M. (2000). Cereal variety and species mixtures in practice, with emphasis on disease resistance. Agronomie, 20(7), 813-837.
12. Friedman, M. (1996). Nutritional value of proteins from different food sources: A review. Journal of Agricultural and Food Chemistry, 44(1), 6-29.
13. Gauffreteau, A. (2018). Using ideotypes to support selection and recommendation of varieties. OCL, 25(6), D602.
14. Hafeez, U., Ali, M., Hassan, S. M., Akram, M. A., & Zafar, A. (2023). Advances in Breeding and Engineering Climate-Resilient Crops: A Comprehensive Review. International Journal of Research and Advances in Agricultural Sciences, 2(2), 85-99.
15. Heslot N, Akdemir D, Sorrells ME, Jannink JL. 2014. Integrating environmental covariates and crop modeling into the genomic selection framework to predict genotype by environment interactions. Theor Appl Genet 127: 463–480.
16. Jones, J. D., & Dangl, J. L. (2006). The plant immune system. Nature, 444(7117), 323-329.
17. Lebedev, V. G., Lebedeva, T. N., Chernodubov, A. I., & Shestibratov, K. A. (2020). Genomic selection for forest tree improvement: Methods, achievements and perspectives. Forests, 11(11), 1190.
18. Lobell, D. B., Schlenker, W., & CostaRoberts, J. (2011). Climate trends and global crop production since 1980. Science, 333(6042), 616-620.
19. Lowry, C. J., & Smith, R. G. (2018). Weed control through crop plant manipulations. In non-chemical weed control (pp. 73-96). Academic Press.
20. Ly, D., Huet, S., Gauffreteau, A., Rincent, R., Touzy, G., Mini, A., ... & Charmet, G. (2018). Whole-genome prediction of reaction norms to environmental stress in bread wheat (Triticum aestivum L.) by genomic random regression. Field crops research, 216, 32-41.
21. Mohammadi, M., Xavier, A., Beckett, T., Beyer, S., Chen, L., Chikssa, H., ... & Wang, W. (2020). Identification, deployment, and transferability of quantitative trait loci from genome-wide association studies in plants. Current Plant Biology, 24, 100145.

22. Munns, R., & Tester, M. (2008). Mechanisms of salinity tolerance. Annual Review of Plant Biology, 59, 651-681.
23. Ortiz-Bobea, A., Ault, T. R., Carrillo, C. M., Chambers, R. G., & Lobell, D. B. (2021). Anthropogenic climate change has slowed global agricultural productivity growth. Nature Climate Change, 11(4), 306-312.
24. Peng S, Khush GS, Virk P, Tang Q, Zou Y. (2008). Progress in ideotype breeding to increase rice yield potential. Field Crop Res 108: 32–38.
25. Peng, S., & Khush, G. S. (2003). Four decades of breeding for varietal improvement of irrigated lowland rice in the International Rice Research Institute. Plant Production Science, 6(3), 157-164.
26. Prost, L., Reau, R., Paravano, L., Cerf, M., & Jeuffroy, M. H. (2018). Designing agricultural systems from invention to implementation: the contribution of agronomy. Lessons from a case study. Agricultural systems, 164, 122-132.
27. Savary, S., Willocquet, L., Pethybridge, S. J., Esker, P., McRoberts, N., & Nelson, A. (2012). The global burden of pathogens and pests on major food crops. Nature Ecology & Evolution, 3(3), 430-439.
28. Smith, C. M. (Ed.). (2005). Plant resistance to arthropods: molecular and conventional approaches. Dordrecht: Springer Netherlands.
29. Teixeira, F. G., Hamawaki, O. T., Nogueira, A. P. O., Hamawaki, R. L., Jorge, G. L., Hamawaki, C. L., ... & Santana, A. J. O. (2017). Genetic parameters and selection of soybean lines based on selection indexes. Genetics and Molecular Research, 16(3).
30. Varshney, R. K., Bansal, K. C., Aggarwal, P. K., Datta, S. K., & Craufurd, P. Q. (2019). Agricultural biotechnology for crop improvement in a variable climate: Hope or hype? Trends in Plant Science, 24(10), 983-997.
31. Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. Ecology and society, 9(2).
32. Wang, W., Vinocur, B., & Altman, A. (2003). Plant responses to drought, salinity and extreme temperatures: Towards genetic engineering for stress tolerance. Planta, 218(1), 1-14.