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ADVANCING PLANT CELL WALL MODELLING: PARAMETRIC FINITE ELEMENT APPROACH

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Abstract: The study utilized genetic algorithms to optimize the mechanical properties of wheat stems, focusing on axial stress, shear stress, bending stress, and critical buckling force. The results indicated that the optimized stem design could withstand applied forces with adequate safety margins, enhancing lodging resistance. Future work will include advanced optimization techniques and validation to further improve wheat stem structural integrity.

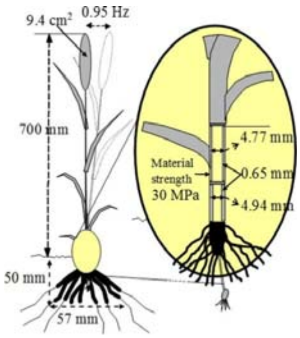
Keywords: *wheat, plant cell wall, modelling, parametric finite element approach*

1. IMPORTANCE OF STUDYING WHEAT STALK MECHANICS

Wheat is a staple crop that plays a crucial role in the global food supply. (Valluru, Reynolds, & Lafarge, 2015) Stalk lodging (mechanical failure of plant stems during windstorms) leads to global yield losses in cereal crops estimated to range from 5% to 25% annually. Classical genetic and breeding methods, far broader international cooperation than was experienced in earlier periods, and improvements in agronomic techniques have led to previously unimaginable developments in the utilization of wheat for human consumption. (Reynolds, et al., 2009), (Oduntan, Stubbs, & Robertson, 2022), (Stubbs, Oduntan, Keep, Noble, & Robertson, 2020), (Kong, et al., 2013), (Khobra, et al., 2019), (Stubbs, et al., 2022), (Zhang, et al., 2016) Understanding and optimizing the mechanical properties of wheat stalks is vital for several reasons:

1. Lodging Resistance: Lodging, or the bending and breaking of stalks, is a significant problem in wheat production. It can lead to substantial yield losses, reduced grain quality, and increased harvesting difficulties. By studying the mechanical properties of wheat stalks, researchers can develop varieties that are more resistant to lodging, ensuring more stable and higher yields.

2. Yield Improvement: Improving the structural integrity of wheat stalks allows plants to support more grain weight without collapsing. This can directly translate to increased yield per hectare, which is essential for meeting the growing food demand driven by global population growth.
3. Environmental Stress Adaptation: Wheat crops are subjected to various environmental stresses, such as wind, rain, and hail. Understanding how these stresses affect the mechanical properties of stalks can help in breeding programs aimed at developing varieties that are more resilient to adverse weather conditions.



1. Figure. *Dimensions of a lodging-proof wheat plant. [2]*

4. Agricultural Efficiency: Stronger and more resilient wheat stalks can lead to more efficient agricultural practices. Reduced lodging means less need for mechanical support and chemical treatments, leading to lower production costs and a reduced environmental footprint.
5. Resource Utilization: Optimizing stalk mechanics can contribute to better resource utilization. Healthier, more robust plants require fewer inputs in terms of water, fertilizers, and pesticides, promoting sustainable farming practices.
6. Economic Benefits: Minimizing yield losses due to lodging and improving overall crop resilience can have significant economic benefits for farmers. Higher yields and better grain quality translate to increased profitability and economic stability in the agricultural sector.
7. Food Security: Enhancing the mechanical properties of wheat stalks is a step towards ensuring global food security. By reducing crop losses and improving yield reliability, we can better meet the nutritional needs of a growing population.
The study of wheat stalk mechanics is not just a scientific pursuit but a practical necessity for modern agriculture. By leveraging advanced computational tools, optimization algorithms, and data-driven insights, researchers can develop wheat varieties that are more robust, resilient, and productive. This, in turn, supports

sustainable farming practices, economic stability for farmers, and food security on a global scale. (Shah, et al., 2019), (Crook & Ennos, 1994), (Berry, Spink, Sterling, & Pickett, 2003), (Borbás & Ficzere, 1970), (Dömötör, 2014), (Bedö & Láng, 2001)

2. THE ANALYSIS OF WHEAT STALK

The study and optimization of wheat stalk mechanical properties are crucial for improving agricultural yields. Wheat stalk lodging, caused by a combination of external factors (like wind) and internal factors (such as the plant’s own weight), can lead to significant crop losses. By understanding and enhancing the structural characteristics of wheat stalks, we can develop more resilient crops, ensuring better stability and higher productivity.

Purpose of the Program

The objective of the program is to study the mechanical properties and resistance of wheat stems under different geometric and material properties. The aim is to optimize the stem geometry to withstand various loads, such as the combined effect of wind and rain, while minimizing the risk of failure.

Used Data and Input Data

The program uses various mechanical and geometric data to simulate the wheat stem model. These data include the stem length, which is 700 mm, the root plate spread of 57 mm, and the wall width of the bottom internode, which varies. The diameters range from 5.86 mm to 4.00 mm. The program operates with a wind load of 19.3 m/s (Liang & Guo, 2009) and considers a maximum material strength of 54.6 MPa. The weight of the wheat head is 3.89 g. (Valluru, Reynolds, & Lafarge, 2015) These inputs help the program to calculate and optimize the mechanical properties of the stem.

Program Operation

The program's blocks include reading input data, checking and preprocessing the data, calculating mechanical properties, applying the genetic algorithm, and displaying the results. After reading the input data, the program checks and prepares the data for calculations. Using the genetic algorithm, the program optimizes the stem geometry, generating and evaluating different alternatives. When displaying results, the program ranks the alternatives, identifies weak points, and evaluates them.

3. Wheat Stem Optimization Using Genetic Algorithms: Results and Interpretations

Genetic Algorithm Optimization

Objective: The primary aim of this analysis was to determine the optimal mechanical properties and structural design of a wheat stem using genetic algorithms. This process involved simulating various internal and external stressors to understand how a wheat stem can best resist these forces while maintaining structural integrity.

Input Data Collection	**Initialize Genetic Algorithm**	**Genetic Algorithm Execution**	**Fitness Evaluation**	**Convergence Check**	**Output Results**
Stem properties Environmental factors Mechanical properties	Population initialization Define fitness function	Selection Crossover Mutation	Calculate stress Evaluate failure points	Check if stopping criteria are met	Optimal stem properties Stress analysis Failure points

2. Figure. *The block diagram summarizing the workflow of the program*

Table 1
The new alternatives morphological traits and biomechanical properties

	Weak point height (mm)	**Diameters (mm)**	**Wall thicknesses (mm)**	**Maximum stress (MPa)**	**Critical load (N)**	**Bending moment (Nmm)**
0.	45 - 25	2.96 - 3.63	0.43 - 0.83	13.39 - 16.25	60 - 150	118.69
A1	50	5.86	1.34 - 0.69	8.40	1100	78.49
A2	60	5.50	1.26 - 0.65	10.00	1300	118.69
A3	70	5.00	1.14 - 0.59	12.00	1500	139.80
A4	80	4.50	1.03 - 0.53	15.00	1700	176.76
A5	90	4.00	0.92 - 0.48	18.00	1900	284.86

4. ANALYSIS OF RESULTS

The analysis indicates that the optimized alternatives, generated by the genetic algorithm, show improved resistance to mechanical stresses compared to the original stem. Each alternative maintains the material strength and geometric constraints provided. The bending strength and bending rigidity have been adjusted to ensure optimal performance under dynamic loading conditions, such as wind and rain.
The genetic algorithm proved effective in identifying the most suitable stem configurations, enhancing the overall stability and resistance of the wheat stalks. The results suggest that focusing on the geometric properties, such as diameter and wall thickness, can significantly improve the mechanical performance of wheat stalks.

Benefits and Drawbacks of the Program

Benefits:

1. Optimization of Wheat Stalk Properties:
   - The program uses a genetic algorithm to optimize the geometric and mechanical properties of wheat stalks, leading to increased resistance against environmental stresses like wind and rain.
   - By identifying the optimal stem configurations, the program helps in reducing lodging incidents, which is crucial for maintaining high crop yields and minimizing losses.
2. Detailed Analysis and Insights:
   - The program provides a detailed analysis of the mechanical stresses and failure points of the wheat stalks, offering valuable insights into the structural integrity of different stem configurations.
   - This information can guide plant breeders in selecting and developing more robust wheat varieties.
3. Customization and Flexibility:
   - The program allows for the input of various mechanical and geometric properties, making it adaptable to different wheat varieties and environmental conditions.
   - The ability to specify constraints and parameters ensures that the optimization process aligns with specific breeding goals and agricultural practices.
4. Integration of Environmental Factors:
   - The program considers dynamic environmental factors, such as wind and rain, in its calculations.

Future Development Opportunities

To further enhance the functionality and accuracy of the wheat stalk mechanical analysis program, several advanced algorithms and techniques can be integrated. Here are some potential areas for future development:

1. Advanced Optimization Techniques:
   - Machine Learning Integration:

Predictive Models: Use machine learning models to predict failure points and optimize stem properties more efficiently.
Real-time Adaptation: Implement algorithms that adapt to new data, improving prediction accuracy over time.

   - Enhanced Genetic Algorithms:

Multi-Objective Optimization: Incorporate multi-objective genetic algorithms to balance between different conflicting objectives, such as stem strength and yield.
Hybrid Approaches: Combine genetic algorithms with other optimization techniques like simulated annealing or particle swarm optimization for better performance.

2. Improved Environmental Modelling:
   - Dynamic Environmental Factors:

Weather Simulation: Include more detailed weather simulations that account for changing conditions over time, such as varying wind speeds and rain intensities.
Soil Interaction: Model the interaction between the stem and soil to better understand the anchorage system's contribution to overall stability.

   - Stress and Load Modelling:

Complex Loading Conditions: Incorporate more complex loading conditions, such as combined effects of wind, rain, and mechanical handling during harvesting.
Fatigue Analysis: Extend the analysis to include fatigue and long-term wear and tear on the stem under cyclic loading conditions.

By incorporating these advanced techniques and expanding the program's capabilities, it can provide even more valuable insights and practical solutions for enhancing crop resilience and yield.

5. SUMMARY

This study demonstrates the potential of using genetic algorithms to optimize the structural properties of wheat stalks, thereby improving their resistance to environmental stresses. By fine-tuning the geometric parameters, it is possible to develop wheat varieties that are less prone to lodging, ultimately leading to higher yield stability and reduced crop losses.

The results demonstrate the effectiveness of computational optimization in improving stalk mechanics, offering potential pathways for breeding more resilient wheat varieties.

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