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Multiscale Fractal Modeling and Structural Analysis of Fracture Regularity in Maize Kernels and Stalks

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Abstract

Fracture behavior in maize kernels and stalks is an important factor influencing mechanical harvesting efficiency, grain quality, postharvest losses, and agricultural machinery performance. Conventional mechanical testing provides information about fracture force, deformation, and energy absorption, but it does not fully characterize the geometric complexity of fracture surfaces. Fractal theory offers a complementary approach for investigating irregular fracture patterns across different observation scales. This paper develops a conceptual framework for multiscale fractal modeling and structural analysis of fracture regularity in maize kernels and stalks. The proposed methodology integrates specimen characterization, controlled mechanical loading, digital fracture imaging, image processing, geometric complexity assessment, and statistical comparison. Particular attention is given to moisture content, anatomical structure, loading orientation, and mechanical threshing conditions as potential factors influencing fracture morphology. The supplied literature establishes the relevance of kernel structure, moisture-dependent mechanical behavior, threshing mechanisms, and discrete-element modeling to this research direction. However, the available references do not provide an experimentally validated fractal model for maize fracture. Therefore, the findings presented here represent a literature-based methodological synthesis rather than measured experimental results. The proposed framework provides a foundation for future investigations into fracture morphology, low-damage harvesting, and agricultural material characterization.

Keywords: Maize kernels, maize stalks, fractal theory, multiscale analysis, fracture morphology, mechanical properties, digital image processing, agricultural engineering, threshing optimization.

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1. Introduction

1.1 Research background

Maize is an important agricultural crop whose harvesting and processing depend on the mechanical properties of kernels, cobs, and stalks. During harvesting, these biological structures experience compression, impact, bending, friction, and repeated contact with machinery components. Such interactions may cause kernel breakage, stalk fragmentation, incomplete grain separation, and reductions in harvested-product quality. Understanding the structural response of maize to mechanical loading is therefore essential for improving harvesting technologies and reducing avoidable crop losses.

Previous research has examined the structural and

mechanical characteristics of maize kernels. Singh et al. (1991) investigated corn kernels as hybrid composite materials, emphasizing the importance of their internal structure in determining mechanical behavior. Wang et al. (2017) examined puncture and in-situ compression properties of maize kernels, demonstrating the relevance of different loading conditions to mechanical characterization. These research directions provide a foundation for investigating how maize tissues respond to external forces and how their fracture patterns may vary under different conditions.

Traditional mechanical testing generally emphasizes measurable responses such as maximum failure force, deformation, and energy absorption. Although these indicators are important, they cannot fully describe the geometric characteristics of a fracture surface. Two maize kernels may fail under similar loading conditions but produce different fracture patterns. One may exhibit a relatively simple crack, whereas another may display branching, irregular boundaries, or multiple interconnected fracture regions.

Fractal theory provides a complementary means of examining this geometric complexity. Rather than considering fracture solely in terms of failure strength, fractal analysis focuses on how structural irregularity appears across different observation scales. When applied carefully, this approach may help characterize differences between fracture patterns that conventional mechanical measurements do not adequately distinguish.

1.2 Research problem

The principal research problem is the limited integration of multiscale fracture morphology with mechanical characterization of maize kernels and stalks. Existing studies address material properties, moisture effects, threshing mechanisms, and machinery performance, but the supplied literature does not establish a validated relationship between fractal descriptors and the mechanical behavior of maize fracture surfaces.

This gap is important because fracture geometry may contain information about structural heterogeneity, loading orientation, and failure mechanisms. However, geometric complexity cannot automatically be interpreted as greater mechanical resistance or more severe damage. Its meaning must be evaluated alongside independent mechanical measurements and specimen characteristics.

A systematic analytical framework is therefore needed to standardize fracture-image acquisition, quantify geometric complexity, compare different specimen categories, and investigate the relationship between fracture patterns and mechanical performance.

1.3 Research objectives

The primary objective of this paper is to develop a conceptual multiscale framework for analyzing fracture regularity in maize kernels and stalks.

The study specifically aims to explain the theoretical basis of fractal fracture characterization, establish a methodological procedure for image-based structural analysis, identify the principal variables that may influence fracture morphology, and propose a means of integrating geometric descriptors with mechanical testing and agricultural machinery assessment.

The significance of this work lies in its potential to extend conventional mechanical characterization through a structured examination of fracture geometry. The framework may support future research on crop-material behavior, threshing-system design, and low-damage harvesting. Its practical value, however, depends on experimental validation.

2. Literature Review

2.1 Structural and mechanical properties of maize

The mechanical behavior of maize kernels reflects their heterogeneous biological composition. Singh et al. (1991) investigated the structure and mechanical properties of corn kernels, providing a basis for understanding why their failure behavior should not be treated as that of a perfectly uniform material.

Wang et al. (2017) examined kernel puncture and in-situ compression, two approaches that expose specimens to different forms of mechanical stress. Puncture produces localized loading, whereas compression distributes the applied force across a broader contact region. These differences may influence crack initiation, propagation, and the final appearance of fracture surfaces.

The distinction is relevant to fractal analysis because fracture geometry depends partly on the mechanism through which failure occurs. A fracture pattern generated by localized penetration may differ substantially from one generated through compression, even when the specimens have similar dimensions and moisture conditions.

Li et al. (2018) investigated the influence of water content on the resistance of corn ears to pressing. Li et al. (2014) examined the relationship between kernel moisture content and manual threshing outcomes. These studies establish moisture as an important variable for mechanical investigation. Nevertheless, the supplied references do not determine how moisture affects fractal dimension or multiscale fracture regularity. Such relationships must be established through direct measurements.

2.2 Mechanical threshing and harvesting performance

Mechanical threshing involves interactions among kernels, cobs, stalks, and machinery components. These interactions determine grain separation, mechanical damage, processing efficiency, and energy consumption.

Li and Gao (2009) investigated corn threshers with different rotational speeds, while Srison et al. (2016) examined operating factors associated with shelling losses and power consumption. Their research areas demonstrate why operating conditions should be documented when evaluating fracture behavior.

Dai et al. (2023) analyzed the dynamic threshing and conveying process for seed corn. Fan et al. (2022) investigated an automatic control system for a corn threshing unit using feed-rate monitoring. Zhao et al. (2023) examined a bionic threshing component optimized through multibody dynamics and discrete-element simulation.

These studies provide an engineering context for the proposed framework. Fractal descriptors could potentially supplement existing measurements by characterizing the geometry of damaged kernels. However, their usefulness would depend on whether they provide additional information beyond conventional measures of breakage, grain loss, and processing performance.

2.3 Discrete-element modeling and structural analysis

Discrete-element modeling is used to investigate the behavior of interacting particles under mechanical loading. Martin et al. (2003) examined particle rearrangement during powder compaction, illustrating the relevance of particle-level modeling to mechanical systems.

In maize processing, Li et al. (2022) investigated a constitutive model for low-damage threshing based on the discrete-element method. Such modeling approaches can support the examination of particle contacts, force transmission, and material movement within harvesting machinery.

However, particle interaction modeling and fractal image analysis serve different purposes. Discrete-element models investigate mechanical interactions according to their contact and material assumptions, whereas fractal analysis quantifies the geometry of observed fracture patterns. Integrating these approaches would require experimental calibration to establish whether simulated behavior corresponds to actual fracture morphology.

2.4 Research gap and theoretical positioning

The supplied literature covers several complementary research areas: kernel structure, moisture-dependent behavior, threshing mechanisms, machinery optimization, and particle-based simulation. Together, these areas establish a strong rationale for investigating fracture morphology within agricultural engineering.

Nevertheless, the available references do not demonstrate an experimentally validated framework linking multiscale fractal descriptors to maize fracture resistance, damage severity, or harvesting efficiency. The proposed research addresses this gap by positioning fractal analysis as a supplementary method for structural characterization rather than a replacement for mechanical testing.

A central theoretical proposition is that fracture patterns may exhibit different levels of geometric complexity across observation scales. The magnitude and interpretation of these differences depend on specimen anatomy, loading conditions, image resolution, and the method used to identify fracture features.

3. Methodology

3.1 Research design

The proposed study uses a quantitative comparative design combining mechanical testing, digital image analysis, fractal characterization, and statistical interpretation. The objective is to determine whether reproducible differences in fracture morphology can be identified among maize specimens exposed to different mechanical conditions.

The methodology is organized into five stages: specimen preparation, controlled mechanical loading, fracture-image acquisition, multiscale structural characterization, and statistical evaluation.

Maize kernels and stalks should be investigated as separate specimen categories before their characteristics are compared. Kernels are compact structures with heterogeneous internal composition, whereas stalks are elongated structures whose response depends on tissue organization, cross-sectional characteristics, and loading orientation. These differences make it inappropriate to assume that the same fracture mechanism operates in both categories.

The framework is presented as a proposed experimental methodology. No original experimental dataset was supplied; therefore, numerical measurements and statistical results cannot be reported as observed findings.

3.2 Specimen selection and preparation

Representative maize kernels and stalk segments should be collected from documented cultivars and growing conditions. Sampling procedures should ensure that the specimens are sufficiently comparable to support meaningful analysis.

Each specimen should be assigned a unique identification code. Relevant characteristics should include moisture content, mass, dimensions, visible defects, and anatomical features. Environmental conditions should be controlled where possible to minimize uncontrolled variation during preparation and testing.

Moisture content requires particular attention because it may influence tissue compliance and failure behavior. Specimens should be conditioned under documented conditions, and moisture should be measured using a consistent procedure.

Kernel samples should be prepared for compression and puncture tests, while stalk samples should be prepared for appropriate loading modes, such as axial compression, transverse loading, or bending. The selected tests should reflect the mechanical conditions relevant to the intended harvesting application.

3.3 Mechanical testing procedures

Mechanical testing should be conducted using calibrated equipment capable of recording force and displacement throughout loading. Each specimen should be tested under a predefined loading protocol, with the loading direction and contact configuration recorded.

The principal mechanical measurements should include failure force, displacement at failure, and absorbed energy. Where appropriate, the extent of visible damage and the proportion of broken kernels should also be documented.

These measurements provide an independent basis for interpreting fracture geometry. For example, specimens with comparable failure forces may produce different fracture boundaries, while specimens with similar geometric complexity may exhibit different resistance to loading.

The distinction is important because a geometric descriptor cannot independently establish whether a specimen is mechanically strong, brittle, or resistant to damage. Mechanical measurements must remain part of the analytical framework.

3.4 Fracture-image acquisition and processing

Following mechanical failure, fracture surfaces should be photographed using calibrated imaging equipment. Image resolution, magnification, lighting, viewing angle, and specimen orientation should be standardized within each experimental group.

Digital images should undergo background correction, specimen identification, and segmentation of the relevant fracture features. Depending on the research objective, the analysis may focus on the fracture boundary, visible crack distribution, or surface-texture patterns.

Image preprocessing must be documented because segmentation choices can influence the measured geometric complexity. Excessive smoothing may remove small structural features, while inappropriate edge detection may create artificial boundaries.

A subset of images should be independently reviewed to assess the consistency of the segmentation procedure. Where feasible, three-dimensional surface scanning may be used to supplement two-dimensional imaging, particularly when surface topography is important to the research question.

3.5 Multiscale fractal characterization

Fractal characterization should examine the geometric complexity of fracture patterns at several observation scales. The box-counting method can be used to estimate how the spatial coverage of a fracture feature changes as the observation grid becomes finer.

In practical terms, the procedure involves placing grids

of different sizes over a segmented fracture image and recording how many grid cells intersect the fracture feature. The relationship between grid size and the number of occupied cells is then examined to estimate a fractal dimension.

For finite digital images, the estimation is restricted by image resolution and specimen size. The selected observation scales should therefore be justified, and the analysis should not assume that every fracture pattern exhibits ideal fractal behavior.

The multiscale procedure should distinguish coarse structural features from intermediate and fine details. Larger cracks may dominate the overall pattern, whereas smaller features may reflect localized separation or surface irregularities. Comparing these scale ranges may reveal whether a single geometric descriptor adequately represents the fracture pattern.

A higher estimated fractal dimension should be interpreted as greater geometric complexity within the selected representation and measurement range, not automatically as greater fracture resistance or more severe damage.

3.6 Statistical analysis and validation

Statistical analysis should compare the geometric descriptors of kernels and stalks under different moisture conditions and loading modes. The analysis should account for biological variation among specimens and, where appropriate, differences between cultivars, collection batches, or testing sessions.

Relationships between fractal descriptors and mechanical measurements should be examined to determine whether geometric complexity provides additional information about failure behavior. Relevant comparisons may include associations with failure force, absorbed energy, and observed kernel damage.

The statistical procedure should include uncertainty estimates, model diagnostics, and sensitivity testing. In particular, researchers should examine whether the results change substantially when image resolution, segmentation parameters, or the selected scale interval is modified.

Independent validation is necessary before the method can be recommended for practical use. A descriptor that distinguishes fracture images under one experimental condition may not perform consistently across different cultivars, moisture levels, or harvesting systems.

4. Results

4.1 Synthesis of the supplied literature

The supplied literature establishes three major foundations for the proposed framework.

First, the structural and mechanical characteristics of maize kernels justify a detailed examination of failure behavior. Research on kernel structure, puncture, and compression provides a basis for considering specimen heterogeneity and loading configuration when interpreting fracture patterns (Singh et al., 1991; Wang et al., 2017).

Second, moisture content and machinery operating conditions are important factors in maize processing. Studies addressing moisture-dependent pressing behavior, threshing losses, and power consumption support the need to control these variables during experimental fracture characterization (Li et al., 2018; Srison et al., 2016).

Third, research on discrete-element modeling, dynamic threshing, and optimized harvesting components provides a potential engineering context for connecting structural observations with processing performance (Li et al., 2022; Dai et al., 2023; Zhao et al., 2023).

These findings establish the relevance of an integrated approach, but they do not demonstrate a specific relationship between fractal dimension and maize fracture behavior.

4.2 Expected outcomes of the proposed framework

The proposed methodology is expected to generate four principal categories of analytical output.

The first is a standardized record of mechanical behavior, including failure force, deformation, absorbed energy, and visible damage. These measurements provide a reference for interpreting differences in fracture morphology.

The second is a set of quantitative geometric descriptors derived from fracture images. These descriptors may help distinguish relatively simple fracture boundaries from more complex patterns involving branching, irregularity, or multiple visible features.

The third is a multiscale characterization of fracture geometry. This analysis may establish whether the observed fracture pattern is adequately represented by a single geometric descriptor or whether its behavior

changes across observation scales.

The fourth is a statistical assessment of the relationship between geometric descriptors and experimental conditions. This assessment may determine whether moisture, loading direction, specimen type, or other documented variables explain differences in fracture morphology.

These outcomes are proposed analytical objectives, not experimentally observed results. Their actual direction and magnitude must be established through controlled testing.

4.3 Interpretation of potential fracture patterns

Differences in fracture morphology may reflect several interacting factors. A localized puncture test may produce a different pattern from compression because the applied force is distributed differently. Similarly, the fracture geometry of a stalk may be influenced by its elongated structure and loading orientation, whereas kernel fracture may be more strongly associated with localized tissue failure and internal heterogeneity.

Moisture may also influence fracture morphology by changing the mechanical response of biological tissues. However, increased moisture cannot be assumed to increase or decrease fractal dimension consistently. Its effect may depend on the specimen, loading condition, and scale of observation.

A meaningful interpretation therefore requires the geometric measurements to be considered alongside independent mechanical results. Fracture images alone cannot establish whether a material has greater strength, absorbs more energy, or produces more consequential damage.

4.4 Research contribution

The primary contribution of this study is the development of a structured procedure for investigating maize fracture geometry through multiscale image analysis. It defines the experimental variables, imaging requirements, analytical stages, and validation procedures necessary for a future empirical investigation.

The framework also establishes a clear distinction between describing fracture morphology and predicting mechanical performance. This distinction is essential if fractal measurements are eventually to be incorporated into agricultural material characterization or harvesting-system evaluation.

Because no original experimental dataset was supplied, this study does not claim measured improvements in fracture prediction, reduced harvesting losses, or statistically significant differences among specimen categories.

5. Discussion

5.1 Implications for fracture characterization

The proposed framework expands the interpretation of maize fracture beyond conventional measurements of force and deformation. Mechanical tests describe how a specimen responds to loading, whereas fractal analysis describes aspects of the geometry produced by failure. Combining these approaches may provide a more complete characterization of material behavior.

This distinction is particularly important when different specimens fail under comparable mechanical conditions but exhibit different fracture patterns. The structural investigations of Singh et al. (1991) and the mechanical testing approaches discussed by Wang et al. (2017) provide a relevant foundation for examining such differences.

Nevertheless, geometric complexity should not be interpreted as a direct measure of mechanical strength. A complicated fracture boundary may result from several mechanisms, and its significance depends on the material, loading conditions, and measurement method.

5.2 Influence of moisture and loading conditions

Moisture content is a potentially important variable because it can affect deformation and failure behavior in biological materials. The studies by Li et al. (2014) and Li et al. (2018) provide relevant context for examining moisture-dependent mechanical behavior and threshing outcomes.

The relationship between moisture and fracture geometry must nevertheless be established experimentally. Changes in moisture may alter the manner in which cracks initiate and propagate, but the resulting geometric pattern cannot be predicted reliably from moisture content alone.

Loading orientation also requires careful consideration. Compression, puncture, and bending expose specimens to different mechanical conditions. Comparisons that do not account for these differences may attribute geometric variation to specimen properties when it is actually associated with the loading procedure.

Future experiments should therefore investigate the independent and combined effects of moisture, specimen anatomy, and loading mode.

5.3 Applications in agricultural machinery

The proposed framework may eventually support the evaluation of mechanical harvesting and threshing systems. Research on shelling losses, operating speed, dynamic seed handling, and optimized threshing components demonstrates the importance of mechanical conditions in agricultural processing (Li and Gao, 2009; Srison et al., 2016; Dai et al., 2023; Zhao et al., 2023).

Fractal descriptors could supplement conventional damage measurements when alternative machinery settings are compared. For example, two configurations might achieve similar grain recovery but produce different fracture patterns among damaged kernels. If those differences were shown to correlate with grain quality or subsequent handling losses, geometric analysis could provide additional information for evaluating machine performance.

Such an application remains hypothetical until validated. The method should demonstrate that it contributes useful information beyond existing measurements of broken kernels, unthreshed grain, processing losses, and energy consumption.

5.4 Integration with computational modeling

Discrete-element modeling may complement fracture-image analysis by providing information about particle interactions and force transmission during threshing. Martin et al. (2003) investigated particle rearrangement during compaction, while Li et al. (2022) examined discrete-element modeling in the context of low-damage corn threshing.

However, simulated particle motion and observed fracture geometry are not equivalent. Their integration would require calibrated material models and experimental comparison between simulated behavior and physical fracture patterns.

A future research program could use experimentally characterized specimens to evaluate whether simulated loading conditions correspond to observed differences in fracture morphology. This would help determine whether fractal descriptors can contribute to the validation of agricultural mechanical models.

5.5 Limitations and future research

The principal limitation is that the present paper proposes a methodology rather than reporting completed experiments. No measured fractal dimensions, specimen-level results, or statistical estimates are available. Consequently, the framework cannot establish the predictive accuracy or practical benefits of fractal analysis.

A further limitation concerns image representation. Two-dimensional photographs may not capture the complete geometry of a three-dimensional fracture surface. Differences in magnification, lighting, and segmentation can also influence the results. Consistent image acquisition and sensitivity testing are therefore essential.

The supplied literature also contains limited direct evidence concerning fractal characterization of maize stalk fracture. Future work should investigate stalks separately, taking into account their anatomical structure and directional mechanical behavior.

Finally, the proposed method should be evaluated across cultivars, moisture conditions, and harvesting environments. Independent validation will determine whether the resulting descriptors are reproducible and practically useful.

6. Conclusion

This paper presents a conceptual framework for multiscale fractal modeling and structural analysis of fracture regularity in maize kernels and stalks. The proposed approach integrates specimen preparation, mechanical testing, digital fracture imaging, geometric complexity assessment, and statistical validation.

The framework emphasizes that fracture morphology and mechanical resistance are related but distinct characteristics. Moisture content, loading orientation, anatomical structure, and harvesting conditions should be investigated as potential factors influencing fracture patterns. Fractal descriptors may complement conventional mechanical measurements, but their practical significance must be demonstrated through experimental validation.

The principal contribution is a systematic methodology for examining fracture geometry at multiple observation scales while maintaining a clear distinction between proposed analytical outcomes and verified experimental findings. The study does not claim that fractal analysis has already improved harvesting efficiency or reduced mechanical damage.

Future research should prioritize controlled experiments, reproducible imaging procedures, robust geometric measurements, and validation against independent mechanical data. Establishing whether multiscale fracture descriptors provide additional predictive or explanatory value could support their eventual application in agricultural material characterization, threshing-system evaluation, and low-damage maize harvesting.

References

1. Astanakulov K D, Kodirov B X. Fozilov G G. Development a new type corn-sheller machine for farms in Uzbekistan. International Journal of Applied Agricultural Research, 2014; 9(2): 115–120.
2. Dai F, Zhao Y M, Liu Y X, Shi R J, Xin S L, Fu Q F, Zhao W Y. Analysis and performance test on dynamic seed corn threshing and conveying process with variable diameter and spacing. Int J Agric & Biol Eng, 2023; 16(2): 259–266.
3. Fan C L, Zhang D X, Yang L, Cui T, He X T, Zhao H H. Development and performance evaluation of a guide vane inclination automatic control system for corn threshing unit based on feed rate monitoring. Computers Electronics in Agriculture, 2022; 194: 106745.
4. Geng D Y, He K, Wang Q, Jin C Q, Zhang G H, Lu X F. Design and experiment on transverse axial flow flexible threshing device for corn. Transactions of the CSAM, 2019; 50(3): 101–108.
5. Khawaja A N, Khan Z M. DEM study on threshing performance of “compression–oscillation” thresher. Computational Particle Mechanics, 2022; 1-16.
6. Li S K, Wang K R, Xie R Z, Ming B. Mechanical kernel harvesting promoted the transformation of maize production mode. Agricultural Science in China, 2018; 51(10): 1842–1844. (in Chinese)
7. Li S K, Wang K R, Xie R Z, Hou P, Ming B, Yang X X, et al. Implementing higher population and full mechanization technologies to achieve high yield and high efficiency in maize production. Crops, 2016; 4: 1–6. (in Chinese)
8. Li X P, Gao L X. Performance test on corn thresher with different-speed threshing parts. Transactions of the CSAE, 2009; 25(12): 102–106. (in Chinese)
9. Li X P, Du Z, Ma Y D. Effect of kernel moisture content to the result of bare hand threshing of corn ear interval. Applied Mechanics Materials, 2014; 644-650: 5285–5290.
10. Li X P, Xiong S, Geng L X, Ji J T. Influence of water content on anti-pressing properties of corn ear. Transactions of the CSAE, 2018; 34(2): 25–31.
11. Li X P, Zhang W T, Xu S D, Ma F L, Du Z, Ma Y D. Calibration of collision recovery coefficient of corn seeds based on high-speed photography and sound waveform analysis. Agriculture, 2023; 13(9): 1677.
12. Li X Y, Du Y F, Guo J, Mao E R. Design, simulation, and test of a new threshing cylinder for high moisture content corn. Applied Sciences, 2020; 10(14): 4925.
13. Li X Y, Du Y F, Liu L, Mao E R, Yang F, Wu J, et al. Research on the constitutive model of low-damage corn threshing based on DEM. Computers Electronics in Agriculture, 2022; 194: 106722.
14. Li Y, Yan B X, Zhang D X, Zhang T L, Wang Y X, Cui T. Research progress on precision planting technology of maize. Transactions of the CSAM, 2016; 47(11): 38–48.
15. Martin C L, Bouvard D, Shima S. Study of particle rearrangement during powder compaction by the discrete element method. Journal of the Mechanics, 2003; 51(4): 667–693.
16. Ouyang A, Fan C L, Zhao H, Dong J Q, Jiao Y X. Present status and equipment research progress of maize full mechanized production. Journal of Chinese Agricultural Mechanization, 2022; 43(6): 207–214. (in Chinese)
17. Singh S, Finner M, Rohatgi P, Buelow F, Schaller M. Structure and mechanical properties of corn kernels: a hybrid composite material. Journal of Materials Science, 1991; 26: 274–284.
18. Srison W, Chuan-Udom S. Design factors affecting losses and power consumption of an axial flow corn shelling unit. Agriculture and Natural Resources, 2016; 38(5): 421–425.
19. Srison W, Chuan-Udom S, Saengprachatanarak K. Effects of operating factors for an axial-flow corn shelling unit on losses and power consumption. Agriculture and Natural Resources, 2016; 50(5): 421–425.
20. Wang K R, Xie R Z, Xue J, Sun L R, Li S K. Comparison and analysis of maize grain commodity quality and mechanical harvest quality between China and the United States. Int J Agric & Biol Eng, 2022; 15(1): 55–61.
21. Wang X, Yan H, Hou J. Study on mechanical properties of maize kernel texture puncture and in-situ compression. Anhui Agricultural Sciences,

2017; 45(11): 210–213, 249. (in Chinese)

22. Yang J Y, Li X, Xie Y, Wang N, Liu W C. Anti-hepatoma activity and mechanism of corn silk polysaccharides in H22 tumor-bearing mice. International Journal of Biological Macromolecule, 2014; 64: 276–280.

23. Zhao J L, Zhao H N, Tang H, Wang X G, Yu Y J. Bionic threshing component optimized based on MBD-DEM coupling simulation significantly improves corn kernel harvesting rate. Computers Electronics in Agriculture, 2023; 212: 108075.