INTEGRATION OF EDEM BY ALTAIR SIMULATIONS FOR EFFICIENT DISTRIBUTION OF LARGE AND SMALL SEEDS IN AGRICULTURAL SYSTEMS OF VINEYARDS AND FRUIT TREES

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INTEGRAREA SIMULĂRILOR EDEM DE LA ALTAIR PENTRU DISTRIBUȚIA EFICIENTĂ A SEMINȚELOR MARI ŞI MICI ÎN SISTEME AGRICOLE DE VIȚĂ DE VIE ȘI POMI FRUCTIFERI

Dragoș-Nicolae DUMITRU[1)], **Eugen MARIN**[1)], **Gabriel-Valentin GHEORGHE**[1)], **Dragoş MANEA**[1)],
Marinela MATEESCU[1)], **Dragoș-Nicolae ANGHELACHE**[1,2*)], **Elisabeta PRISACARIU**[1)], **Alin HARABAGIU**[1)]
[1)]INMA Bucharest/ Romania
[2)]National University of Science and Technology POLITEHNICA Bucharest/Romania
E-mail: dumitrudragos.nicolae@gmail.com; dragos1989anghelache@gmail.com

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ABSTRACT

Efficient seed distribution is crucial for maximizing crop yields in agricultural systems, particularly in vineyards and orchards where both large and small seeds are used. This research investigates the integration of EDEM by Altair simulations to enhance the distribution process of these seeds. Utilizing discrete element modeling (DEM), the study provides a comprehensive analysis of seed behavior during dispersal, including interactions with varying terrain and environmental conditions. Through detailed simulations, the research identifies critical parameters that influence seed placement accuracy, such as seed size, distribution patterns, and environmental factors. The results reveal that EDEM simulations can optimize the distribution of seeds, leading to reduced seed wastage and improved crop density uniformity. This integration not only facilitates a more precise sowing process but also offers valuable insights into the dynamics of seed distribution in complex agricultural systems. The findings suggest that adopting this simulation technology can significantly advance precision agriculture practices, offering tangible benefits for the efficiency and productivity of vine and fruit tree cultivation.

REZUMAT

Distribuția eficientă a semințelor este crucială pentru maximizarea randamentelor culturilor în sistemele agricole, în special în podgorii și livezi unde sunt folosite atât semințe mari, cât și mici. Această cercetare investighează integrarea EDEM prin simulările Altair pentru a îmbunătăți procesul de distribuție a acestor semințe. Folosind modelarea cu elemente discrete (DEM), studiul oferă o analiză cuprinzătoare a comportamentului semințelor în timpul împrăștierii, inclusiv interacțiunile cu terenul și condițiile de mediu variate. Prin simulări detaliate, cercetarea identifică parametrii critici care influențează acuratețea plasării semințelor, cum ar fi dimensiunea semințelor, modelele de distribuție și factorii de mediu. Rezultatele arată că simulările EDEM pot optimiza distribuția semințelor, ceea ce duce la reducerea pierderii de semințe și la o uniformitate îmbunătățită a densității culturii. Această integrare nu numai că facilitează un proces de însămânțare mai precis, dar oferă și perspective valoroase asupra dinamicii distribuției semințelor în sistemele agricole complexe. Descoperirile sugerează că adoptarea acestei tehnologii de simulare poate avansa în mod semnificativ practicile agricole de precizie, oferind beneficii tangibile pentru eficiența și productivitatea cultivării viței de vie și a pomilor fructiferi.

INTRODUCTION

In modern agriculture, precision in seed distribution plays a pivotal role in optimizing crop yields, particularly in specialized systems such as those used for vines and fruit trees. Accurate placement of seeds is essential not only for maximizing productivity but also for ensuring uniform plant growth and efficient resource utilization. However, the task of distributing seeds evenly becomes increasingly complex when dealing with a variety of seed sizes, ranging from large fruit tree seeds to smaller vine seeds. Traditional seeding methods often encounter challenges in achieving uniform distribution, leading to issues such as uneven growth, reduced yield, and increased wastage.

Recent advancements in simulation technology have introduced innovative solutions to these challenges. One such advancement is the integration of the Discrete Element Method (DEM) by Altair, a powerful tool for modeling and analyzing granular flow and seed behavior.

EDEM by Altair offers advanced capabilities for simulating the dynamics of seed movement within seeding systems, providing critical insights into how seeds interact with different seeding mechanisms. This simulation technology enables researchers to refine and optimize seeding devices, enhancing their performance and accuracy in handling both large and small seeds.

The optimization of the sowing period is crucial for enhancing the speed, seed quality, and overall yield of crops. As highlighted by *An X. et al., (2023),* current agricultural practices face significant challenges, including uneven seed distribution, crowded seedling growth, and high leakage rates during planting. While mechanical seeders offer stability, they often struggle with consistency in seed placement, and pneumatic seeders, although more precise, are energy-intensive and unstable. To address these issues, the development of a centrifugal wheat strip seeding device has emerged as a promising solution for improving high-speed seeding efficiency.

Recent advancements in simulation technology, particularly Computational Fluid Dynamics (CFD) and Discrete Element Method (DEM), have significantly contributed to the optimization of agricultural equipment. In this context, *Cârlescu P. et al., (2022),* emphasized that drying is the most common method for preserving corn seeds, albeit requiring substantial energy and time. The integration of CFD and DEM enables the design and simulation of more efficient dryer models, allowing for enhanced understanding of gas-solid interactions. In their study, the RNG k-ε turbulence model was utilized to effectively simulate fluid flow while analyzing the behavior of maize seeds as assemblies of spheres. The results indicated that a truncated cone-shaped dryer, optimized for airflow velocities, significantly improved both pneumatic transport and seed drying efficiency.

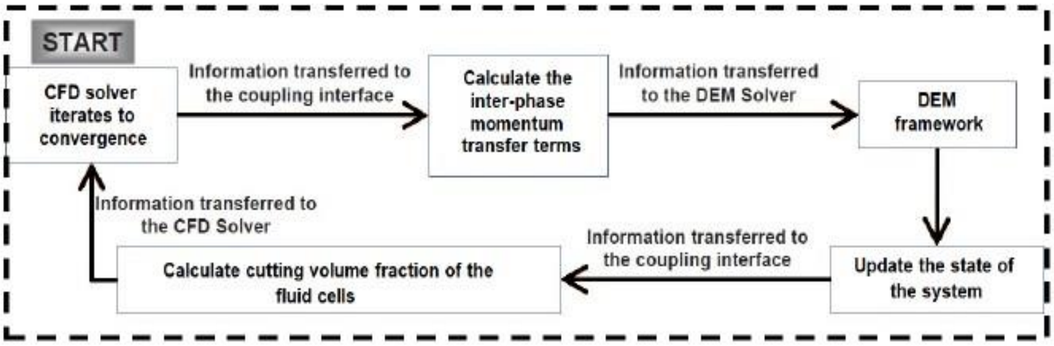


Fig. 1 - Coupled simulation of CFD-DEM

(Cârlescu P. et al., 2022)

Figure 1 illustrates a computational process that integrates CFD (Computational Fluid Dynamics) and DEM (Discrete Element Method) solvers. The process begins with the CFD Solver Iteration, where the CFD solver iterates until it achieves convergence. Next, the information is sent to the Coupling Interface, which calculates the inter-phase momentum transfer terms. The data is then transmitted to the DEM Solver, which updates the system's state. The Feedback Loops indicate that information is exchanged between the DEM framework and the CFD solver, as well as within the CFD solver itself, involving the calculation of fluid cell cutting volume fractions. This iterative approach ensures accurate simulations by continuously updating and sharing information between the solvers.

Moreover, the application of EDEM for modeling the behavior of wheat grains further enhances our understanding of the filling process during sowing. *Song C. et al., (2021),* investigated the size and behavior of wheat grains through precise measurements, which were then used to create a three-dimensional map for simulation. Their findings revealed that the API automatic filling model demonstrated higher accuracy in replicating real wheat grains compared to manual filling models, with an error margin of only 3.08%. This underscores the importance of accurate modeling in improving the effectiveness of seed metering devices.

This article presents a comprehensive study on the integration of EDEM simulations by Altair to address the complexities associated with distributing various seed sizes in agricultural systems tailored for vines and fruit trees.

By employing sophisticated modeling techniques, this research aims to improve the precision of seed distribution processes, thereby advancing planting strategies and contributing to more efficient crop management. The study examines the impact of these simulations on optimizing seed flow dynamics, reducing distribution errors, and enhancing the overall effectiveness of seeding equipment. Through detailed analysis and validation, the research seeks to offer practical solutions for achieving uniform seed distribution and improving the operational efficiency of agricultural systems.

MATERIALS AND METHODS

Equipment and System Design

Cheng B. et. al., (2022), study highlights the importance of precision in fertilizer application to improve efficiency. Traditional mechanical systems often suffer from blockages and uneven distribution, especially in multi-row setups. While pneumatic systems offer better efficiency, research on fertilizer particle movement is limited. This study designs and evaluates a pneumatic fertilizer discharge system, incorporating a distributor, corrugated pipe, elbow, fertilizer box, quantifier, jet feeder, and fan. High-speed airflow is used for mixing and transport. Simulations with EDEM-FLUENT confirmed smooth particle movement and minimal backflow. Bench tests at 35–40 m/s wind speed showed fertilization efficiencies of 0.29–0.41 kg/s and consistent row discharge, achieving stable, multi-row application.

The article by *Han D. et al., (2018),* highlights the global significance of maize as an essential crop for animal feed, medicine, and chemical production. In China, where annual maize production surpasses 200 million tons, precision planting is vital for maximizing seed utilization and yield. Han D. and his team developed and simulated a pneumatic maize seed-metering device, illustrated in Figure 2, using EDEM software. This device, modeled with six components and analyzed through EDEM-CFD simulations, demonstrated strong alignment with experimental data. The study identified optimal design parameters, including a lower lateral hole position, a hole width of 2.0 mm, and an arc length of 10 mm, enhancing performance while minimizing pressure loss. These insights form a basis for advancing pneumatic seed-metering device designs.

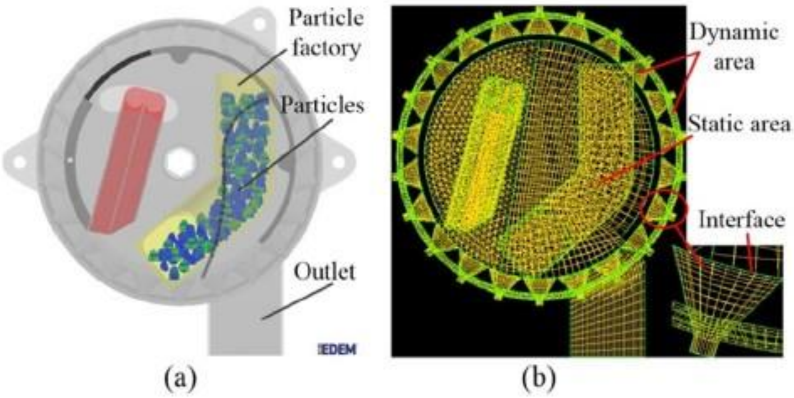


Fig. 2 - 3D simulation models, including a simplified EDEM model of the seed metering device.
(Han D. et. al., 2018)

The study by *Sun J. et al., (2020),* investigates the grooved-wheel drilling device, which is widely used for seeding and fertilizing in developing countries due to its cost-effectiveness and versatility. Despite its popularity, the device encounters challenges such as particle breakage and wheel jamming, which impact precision. To enhance its performance, Sun J. and his team used EDEM simulation software to analyze particle velocity and force during operation. To validate these simulations, a new grooved wheel was created using 3D printing. The team employed a custom-built experiment bench to measure fertilizer distribution and optimize the device. For accurate simulations, spherical particles and the Hertz-Mindlin contact model were utilized.

The grape industry's significance in regions with harsh winters, such as Central Asia, is emphasized due to the labor-intensive vine-burying practices commonly used. *Yang Q. et al., (2021),* address the limitations of traditional vine-digging machines, which often lack precision and risk vine damage. To enhance efficiency and minimize damage, the study proposes a non-contact blower designed to remove soil from grapevines using air flow. The design and performance of the blower were evaluated using EDEM and CFD software, with a 22kW centrifugal fan serving as the prototype. Field tests conducted in Ningxia, China, demonstrated that the blower successfully cleared over 70% of soil in low moisture conditions and 80% under typical field conditions, achieving an average efficiency of 77.10% without damaging the vines.

System Configuration and Parameter Optimization

Ding H. et al., (2019), developed a fertilizer guide device aimed at ensuring uniform application aligned with seed lines. Using EDEM software, they optimized key design elements such as the shunt part angle (33°), vertical distance (76 mm), and horizontal position (25 mm), which significantly improved fertilizer distribution, with minimal impact from the groove angle. These findings, validated through simulations and experiments, offer valuable insights for enhancing agricultural practices. Similarly, *Ding S. et al., (2018),* optimized a dual-band fertilizer applicator shown in Figure 3, which applies starter and base fertilizers separately to improve nutrient utilization and cost-effectiveness. Their design, featuring a two-compartment hopper, fluted roller, and adjustable tubes, demonstrated through DEM simulations and tests that precision, uniformity, and efficiency were improved, reducing costs.

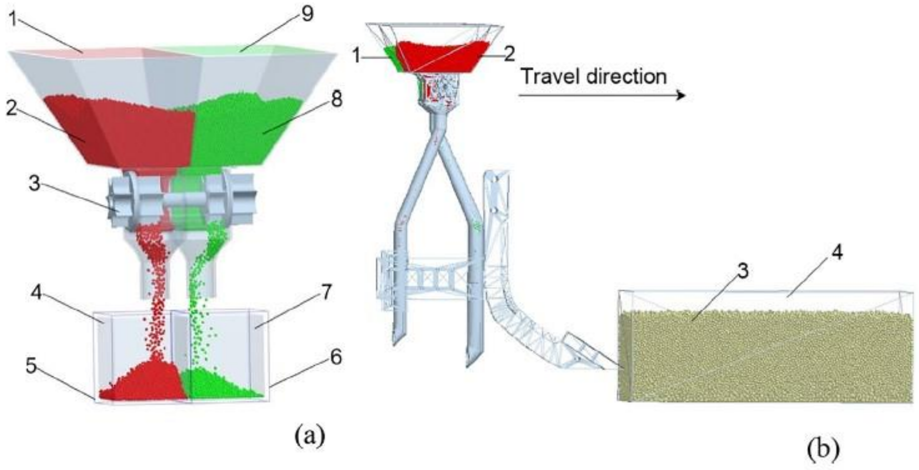


Fig. 3 - EDEM working model
(Ding S. et al. 2018)

The system presented in Figure 3 includes (a) working model of the metering assembly with components such as 1 - the starter fertilizer compartment, 2 – stater fertilizer, 3 - fluted roller, 4 – starter fertilizer collection boxes, 5 - monitoring zones for starter fertilizer, 6 - monitoring zone for base fertilizer, 7: base fertilizer collection box, 8: base fertilizer, 9: base fertilizer compartment along with (b) integrated model for fertilizer metering and banding that 1 - features base fertilizer, 2 - starter fertilizer, 3 - soil particles, and 4 - soil bin.

The study by *Zou H. et. al., (2023),* highlights the need for improved sowing accuracy in agriculture, noting that domestic equipment typically achieves 90-95% accuracy compared to up to 98% with foreign technology. To address this, a new seed reseeding device is introduced shown in Figure 3, featuring a needle seeder and electromagnetic vibration mechanism to enhance suction and reduce missed seeds. Optimal settings include an inlet speed of 8 m/s, a 1.8 mm aperture, an 18 mm lead, and a V-shaped nozzle. Simulations with EDEM and ANSYS/Fluent confirmed these settings, resulting in improved suction efficiency and precision. The device effectively handles about 4 seeds, significantly boosting sowing accuracy and efficiency.

Mechanical and air-suction seed metering devices for soybean cultivation in Northeast China were compared in a study by *Dun G. et al., (2022).* While mechanical devices are more affordable, they tend to be less precise, whereas air-suction devices provide higher accuracy but come with increased power consumption. Dun G. and the team conducted simulations to determine the optimal parameters for the seed-metering wheel, achieving over 90% single-seed accuracy, which was validated through bench tests. Similarly, *Jia H.L. et al., (2018),* focused on high-speed precision seeding, developing an agitated seed metering device that outperformed traditional units. Optimized parameters improved speed and accuracy, reaching a qualified seeding index of 93.9%. Lastly, *Wang J. et al., (2017),* introduced a ripple surface pickup finger design for maize seed metering, resolving issues related to seed size and shape variations. The optimized design improved performance by 12.34%, confirmed by both simulations and tests.

In their study, *Lei X. et al., (2016),* emphasized the importance of precision planters for rapeseed and wheat in China's Yangtze region, particularly focusing on centralized pneumatic planters. By employing DEM-CFD simulations, Lei X. and the team optimized the air-assisted seed metering system, determining the ideal airflow velocity and throat length for efficient seed movement. Similarly, *Li K. et al., (2023),* introduced a fan-driven airflow system for high-speed sowing in Xinjiang's arid climate, optimizing the seed delivery pipeline for better precision. Their CFD-DEM simulations identified a 15° pipe angle and round table diversion, achieving high seeding accuracy and minimal missed seeds. *Liu R. et al., (2022),* addressed challenges in high-speed maize planting, using DEM-CFD simulations to optimize seed ejection parameters like intake position, angles, and airflow velocity. Their innovations improved seed spacing and ejection speed, essential for precision planting.

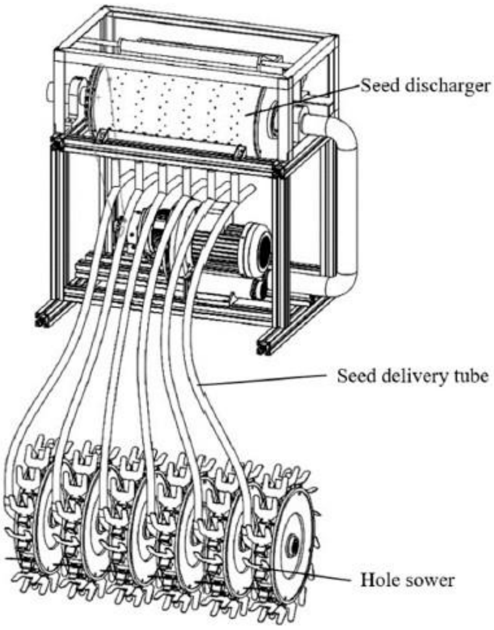


Fig. 4 - Split seeding system
(Lu B. et al. 2022)

Centralized seed metering systems for maize were the focus of a study by *Lu B. et al., (2019),* presented in Figure 4, which highlighted their relevance for modern precision farming. They employed EDEM and CFD simulations to analyze seed flow dynamics and improve the metering system's performance. The research pinpointed the optimal combination of airflow rate and seed inlet angle, leading to smoother seed movement and increased planting accuracy. Bench tests validated the simulation results, confirming improved uniformity in seed distribution. Similarly, *Ma C. et al., (2023),* improved corn planting efficiency with a belt-type seed guide device that reduces collisions and ensures uniform discharge. Optimized with simulations, the device's key parameters, like a 560 r/min wheel speed, enhanced high-speed sowing. *Ma W. et al., (2023),* focused on mechanized seeding for sesbania, using DEM simulations to optimize seed dynamics. Their study identified key factors affecting seed movement, with a model validation error of only 2.74%, ensuring accuracy.

Ren D. et al., (2022), optimized a hazelnut harvester cleaning device for mountainous regions, achieving a 95.12% net fruit rate through CFD and DEM simulations. *Shi L. et al., (2023),* used DEM to improve quinoa seeding machinery by analyzing seed properties and friction, boosting efficiency. *Sun S. et al., (2024),* introduced a vibrational seed supply system for irregular seeds like peppers, reaching 90.75% single-grain accuracy. *Tang H. et al., (2022),* enhanced maize seeding by optimizing the seed drop tube in a precision device, improving uniform seed delivery and performance. *Wang H. et al., (2022),* developed a precise garlic seed-metering device, achieving a 91.86% single-seed rate using EDEM simulations. *Wang S. et al., (2022),* improved sunflower seed harvesting by comparing DEM models, finding cuboid models most accurate for seed dynamics. *Wang Y. et al., (2023),* optimized soybean planting with a friction-based seed-filling method, showing that friction and particle size improve seeding efficiency. *Zhao J. et al., (2024),* optimized pneumatic seed delivery systems using DEM and CFD simulations, reducing pressure loss and enhancing seed distribution uniformity.

Mechanization and Performance Evaluation

Guo H. et al., (2021), emphasized the economic importance of garlic in China and the need for mechanization to improve sowing efficiency. They introduced a garlic seed metering mechanism optimized for single-seed accuracy, achieving over 80% accuracy in field tests. To enhance the efficiency of rice planting with seedling transplanting machines, *Wang J. et al., (2020),* examined prevalent issues such as seedling damage and low planting accuracy. They designed an innovative gripper mechanism aimed at ensuring gentle handling and precise placement of seedlings. Both simulations and field tests revealed that this new mechanism significantly reduced damage rates and improved planting accuracy over traditional models. These findings indicate the mechanism's strong potential to improve overall transplanting performance. *Guo J. et al., (2002),* developed a high-speed mechanical corn planter with an inclined seed-metering device. DEM simulations and field tests showed a 92.83% qualified seeding rate and low error rates, confirming the planter's efficiency and meeting industry standards.

The benefits of mixed sowing oats and vetch was explored by *Liao Y. et al. (2023)* for improved yield and soil fertility, focusing on optimizing air-blowing seed-metering devices for small forage seeds. Using DEM-CFD simulations, they identified optimal parameters, such as a 60° seeding angle and air velocity of 35-40 m/s, to enhance seed movement and distribution. Bench tests validated the results. Another study by *Liao Y. et al., (2023)*, talks about optimized pneumatic seeders for oats and vetch, achieving the best consistency at 25 m/s airflow velocity through DEM-CFD simulations, ensuring uniform distribution. *Li Y. et al., (2020),* reviewed advancements in cotton seeders, highlighting that, mechanical devices optimized with cushioning and retracting spoons, can achieve over 93% precision. Simulations and tests confirmed optimal performance at 50 r/min and a 15° tilt, making the spoon-wheel device highly effective for cotton sowing.

Liu J.S. et al., (2020), optimized fertilizing machinery for alfalfa, which is underutilized in China despite its high protein content. Using EDEM simulations and orthogonal experiments, the study improved fertilization uniformity by 18.9%, with optimal parameters of 16 mm knob-width, 45° slanting angle, and 27.5 mm horizon-distance. *Ma D. et al., (2024),* improved DEM simulations of wheat seed dynamics by using the multi-sphere method, finding that a 0.32 mm filling ball radius achieved the best accuracy with a 6.54% error rate. *Ma W. et al., 2022,* designed an alfalfa seed airflow collection system, optimizing the Venturi ejector to improve seed mobility and feeding efficiency, validated by experimental tests. *Miao Z. et al., (2019),* focused on precision seeding for afforestation using air-suction seeders. EDEM simulations identified the best vibration settings (20 Hz, 5 mm amplitude), improving seed suction and distribution accuracy.

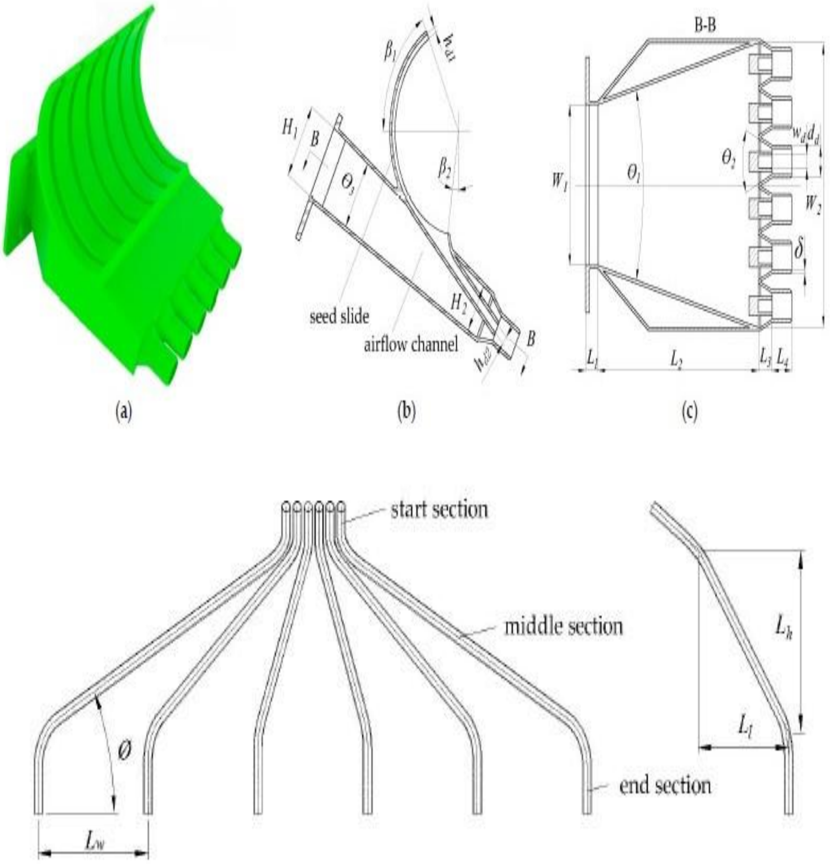


Fig. 5 - Structural design of the distribution manifold
(Wang B. et. al. 2023)

Wang B. et. al., (2023), study highlights sesame's significance as an oil crop and the limitations of traditional seeding methods, which often lead to uneven distribution. Single-seed seeding requires additional coating, while hill-seeding provides better distribution without it. The research develops an air-assisted seed-guiding device to enhance seeding quality and uniformity, addressing issues like poor seed mobility and tube blockages. The device shown in Figure 5, featuring a blower, manifold, and seed tubes, was optimized through CFD-DEM simulations and bench tests, achieving an 86.80% qualified rate and 6.00% miss-seeding rate. Field tests confirmed its effectiveness, with an average of 1.32 seedlings per hill and an 83.45% qualified rate, meeting precision hill-seeding requirements for sesame.

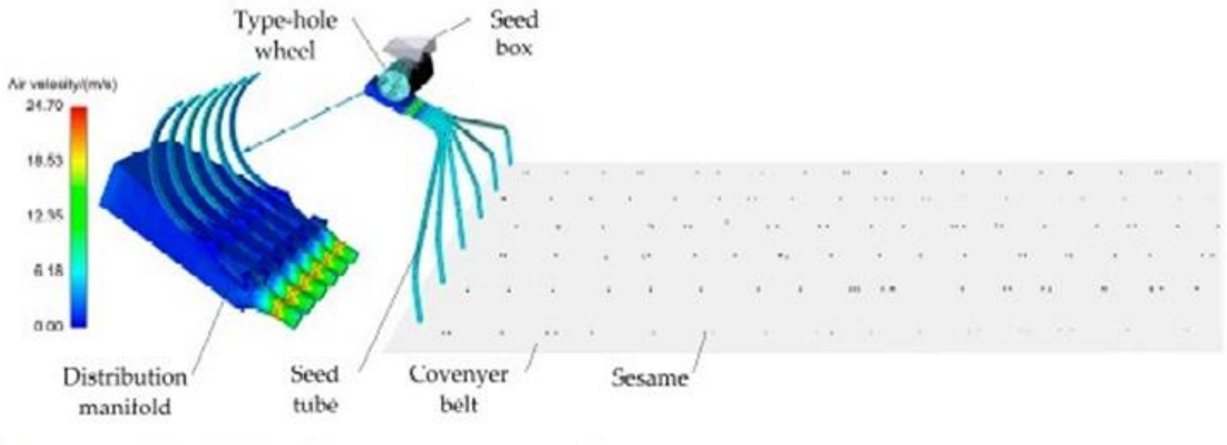


Fig. 6 - CFD-DEM simulations and bench tests
(Wang B. et. al., 2023)

Wang J. et al., (2024), optimized a side-filled rice precision seeder to minimize seed damage and improve hole formation. Using DEM and MBD simulations, along with high-speed camera analysis, they determined that a rotation speed of 47 r/min, a 19° seeding angle, and a 180 mm seeding height provide optimal performance. *Wang M. et al., (2022),* focused on improving sugarcane billet planters, using DEM simulations to optimize the seed-filling process. They found that a 117° rake bar angle and increased billet presence near the rake bar improved seed-filling uniformity. *Wang L. et al., (2024),* enhanced mechanized wheat planting by optimizing air-assisted seeding technology. DEM simulations showed that heptagon and pentagon wheels increased seed fluidity and stability, with higher feeding speeds further improving seed distribution. These advancements are vital for improving the efficiency of wheat and rice planting machinery.

Xiao Y. et al., (2022), emphasized the importance of uniform seeding in rapeseed planting, noting that an air-feeding seed metering system can improve efficiency. They used DEM-CFD simulations to compare different seed tube structures—corrugated, hole-type, and round tubes—finding that corrugated and hole-type tubes enhanced seed distribution, although hole-type tubes resulted in more collisions. *Yan D. et al., (2021),* proposed a new Discrete Element Method (DEM) approach for better soybean particle modeling, identifying that multi-ball models (five, nine, and thirteen balls) improve simulation accuracy, especially for less spherical particles. In a subsequent study, *Yan D. et al., (2022),* focused on calibrating rolling friction coefficients for soybean seeds, using 5-, 9-, and 13-sphere models. Their findings indicated that precise measurement of rolling friction is crucial for accurate simulations, with high accuracy confirmed through multiple tests.

Zha X. et al., (2020), propose a six-row pneumatic deep precision fertilization device for rice transplanters to address issues like fertilizer waste and uneven growth in traditional methods. Featuring a spiral distribution system and precise control through sensors and PID, the device showed a high accuracy rate, with only a 3.53% error in tests. *Zhang B. et al., (2024),* introduced a new sugarcane seed metering device to solve problems like blockages and seed damage. With compliant walls and vibration relief, the device improved seed flow, boosting discharge rate by 43.7% and reducing blockages, leading to better accuracy and efficiency.

Zhang X. et al., (2022), developed a pneumatic seeder for single-seed precision planting. They identified optimal parameters using Ansys Fluent: a 15 mm air pipe diameter, a 105° angle, and a 34 mm negative pressure aperture. Their tests achieved an average airflow velocity of 102.59 m/s, reducing pressure loss and improving efficiency by optimizing airway structures. *Zhao X. et al., (2022),* addressed challenges in strip sowing for wheat, proposing a new seed metering device that uses positive and negative pressures to enhance seed uniformity and minimize damage. Their device features a roller with five rows of 2.0 mm holes and achieved an 80.62% qualified seeding rate with low reseeding (9.22%) and miss-seeding (10.16%) rates, meeting industry standards.

Both the integration of electromechanical actuators in agricultural excavator booms and the utilization of EDEM simulations for seed distribution aim to improve the efficiency of agricultural machinery. The primary focus of integrating electromechanical actuators is to optimize movement and power use, which directly impacts the machine’s operational performance and battery life. The optimization of actuators ensures that agricultural machinery, such as excavator booms, operates smoothly and requires less power *Savaniu et. al., (2023)*. This is crucial for electric and hybrid agricultural machines, which benefit from extended operational periods due to improved energy management.

Vending Machine Mechatronics employ microcontrollers and sensors to ensure that dose delivery is accurately monitored and adjusted based on real-time data *Savaniu et. al., (2024)*. The integration of feedback loops enables the machine to adapt to different conditions, maintaining consistent energy use and reducing waste. Similarly, EDEM simulations can be integrated with planting equipment's control systems to optimize the seeding process. Real-time data from sensors about soil conditions, terrain, and seed type can inform the equipment's operation, ensuring that the seed distribution is energy efficient and precise.

Mechatronic Delivery system in vending machines is designed to use minimal energy while maintaining effective product delivery. The spiral mechanism ensures precise control over the portioning and release of products, allowing for energy-efficient operation. The study of energy consumption within this context highlights how different components interact to optimize power use *Savaniu et. al., (2024).*

Also, *Zhu H. et al., (2023),* tackled issues with no-till planters affected by vibrations from straw and root stubble. They proposed a shaftless spiral seed discharge device that improves seed delivery on uneven terrain. Field trials showed this device outperformed traditional methods, meeting no-till standards and enhancing performance under high-vibration conditions.

For this study, a complex design and simulation process were developed, starting with making a seed distributor using SolidWorks modeling software. The spreader design has been created with the goal of achieving even and efficient distribution, taking into account factors such as seed size, distribution speed and soil type. SolidWorks was chosen because of its ability to generate accurate and detailed models, facilitating both distributor structure analysis and component performance evaluation. To validate the efficiency of the spreader and to simulate the seed distribution process on the soil, the software EDEM by Altair was used, a simulation program based on the discrete element method (DEM). This technology is particularly useful in simulating the movement and interaction of small particles such as seeds in a complex environment such as soil. The simulation in EDEM allowed us to analyze with great accuracy the behavior of the seeds as they are transported through the hose and reach the soil. This approach provided us with relevant data on the trajectory of the seeds, their fall speed, as well as the distribution on the soil surface. Based on the results obtained from the simulations, iterative adjustments to the model were performed in SolidWorks, testing the improvements through additional simulations in EDEM. This iterative design and testing process enabled the distributor design to be gradually optimized, ensuring the efficiency and reliability required for use in real-world agricultural application conditions.

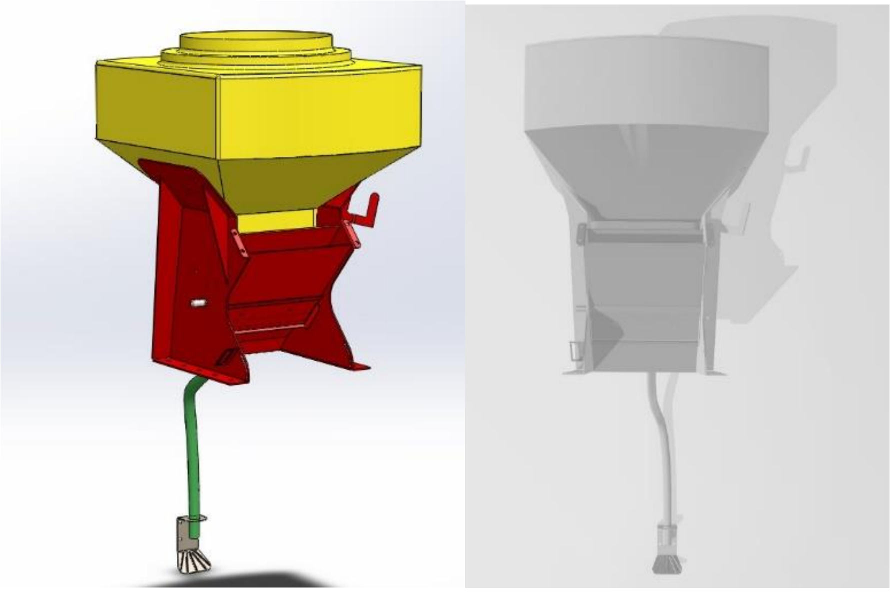


Fig. 7 - Seed distributor with SolidWorks Software

Figure 7 shows the model of the seed distributor made in SolidWorks, together with its version in STL format, ready to be imported into the EDEM by Altair simulation software. For the simulation, three distinct types of seeds were selected:

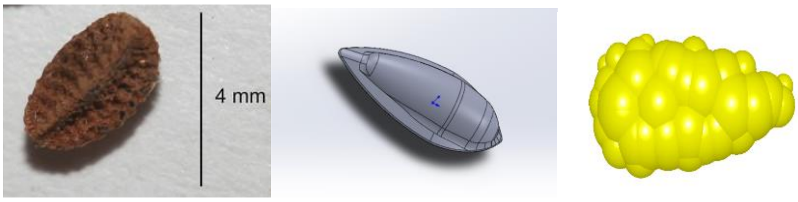


Fig. 8 - Phacelia tanacetifolia seed
(https://gobotany.nativeplanttrust.org/species/phacelia/tanacetifolia/)

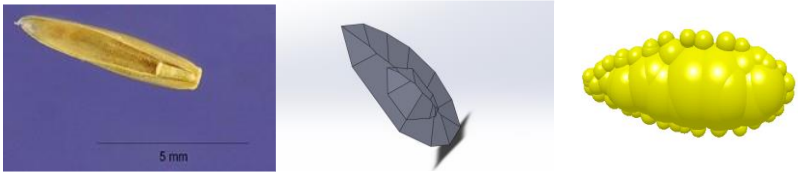


Fig. 9 - Lolium perenne seed
(https://keyserver.lucidcentral.org/weeds/data/media/Html/lolium_perenne.htm)

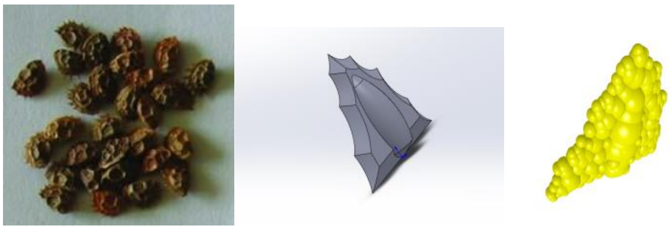
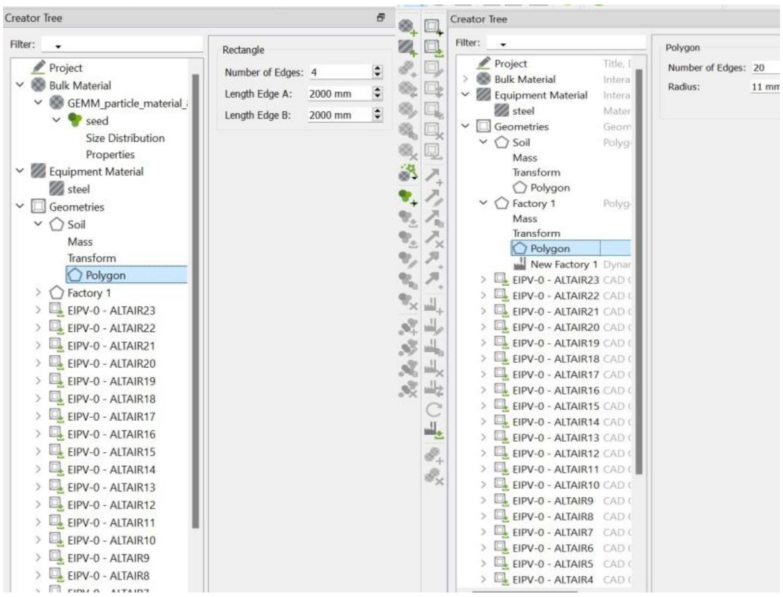


Fig. 10 - Onobrychis viciifolia seed
(https://www.researchgate.net/figure/Onobrychis-viciifolia-seed-variability-1208-1292-1257-and-1126-correspond-to-different_fig2_231803498)

In figures 8, 9 and 10 types of seeds are presented: Phacelia tanacetifolia, Onobrychis viciifolia and Lolium perenne. To ensure the most accurate simulation, detailed CAD models of each seed type were created, which were imported into EDEM by Altair. This approach allowed us to generate particles with characteristics specific to each type of seed, thus optimizing the accuracy of their distribution simulation.



Rectangle
Number of Edges: 4
Length Edge A: 2000 mm
Length Edge B: 2000 mm

Polygon
Number of Edges: 20
Radius: 11 mm

Fig. 11 - Soil and factory in creator tree

In the creator tree presented in Figure 11, polygons are utilized to model both the soil and the factory for the simulation of seed distribution. First, a polygon is created to represent the soil, which serves as the primary environment where the seeds will be dispersed. This polygon outlines the boundaries of the soil area, providing a clear visual representation of the terrain in which the simulation occurs.

Next, a second polygon is designed for the factory, which acts as the origin or source of the seeds. The factory is positioned near the soil, symbolizing where the seeds are coming from before they are scattered onto the field. These polygons are crucial because they not only define the spatial elements of the simulation but also set the stage for modeling seed movement and distribution across the defined landscape. Once the soil and factory polygons are in place, the simulation is initiated by distributing seeds within the soil polygon. The seeds are randomly placed within the soil boundaries, imitating the natural process of sowing. This simulation allows visualizing how the seeds are spread over the terrain, offering insights into patterns of distribution and helping to assess potential coverage of the area.

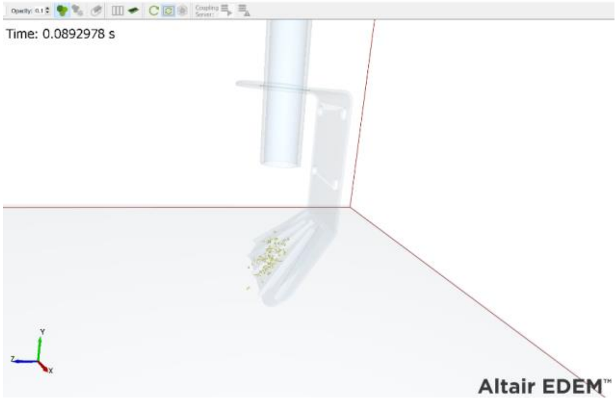
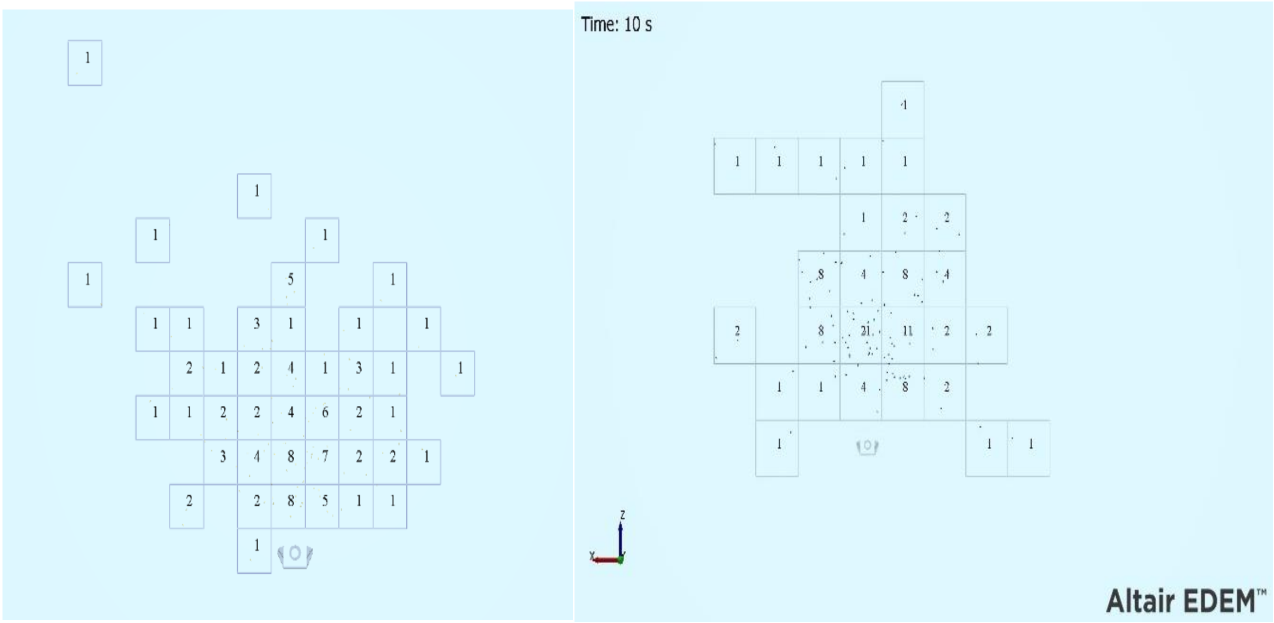


Fig. 12 - Interaction between seed-distribution board

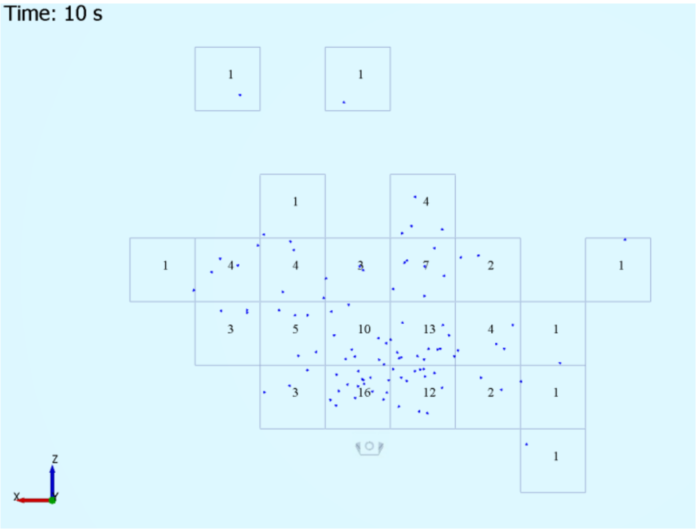
In Figure 12 the interaction between the seeds and the distribution board is presented, during the seeding process. The distribution board is positioned at a 45º angle, which plays a critical role in directing the seeds as they make contact with the board. This angle helps ensure that the seeds are efficiently distributed across the soil surface by optimizing their trajectory after collision, promoting a more uniform spread. The 45º inclination is specifically chosen to balance the forces acting on the seeds during impact, minimizing bounce or clumping and enhancing overall seeding efficiency.

RESULTS

In this section, the results of a 3D scatter plot representing the spatial distribution of seeds within the defined area are presented. A detailed quantitative analysis has been conducted, focusing on several key aspects: density analysis, variance in seed distribution, hotspot identification, and standard deviation.



a) 3D Scatter plot Phacelia tanacetifolia *b) 3D Scatter plot Lolium perenne*



c) 3D Scatter plot Onobrychis viciifolia

Fig. 13 - 3D Scatter plot for the seeds

In figure 13 a) and b), the highest seed concentration is marked by the number 10, positioned in the bottom left quadrant of the image. Figure 13 c) displays a grid composed of multiple squares, each containing a varying number of dots to represent seeds. The arrangement suggests a symmetrical distribution, with the middle row showing the densest seed concentration.

A quantitative analysis was conducted based on a 3D scatter plot for Onobrychis viciifolia seeds generated using EDEM software by Altair. The analysis involved converting the 3D seed data into a simplified 2D grid format presented in Table 1, where each cell in the grid represented the number of seeds within a corresponding square area of the plot.

Table 1

2D grid for 3D scatter plot Onobrychis viciifolia

Square Number	**1**	**2**	**3**	**4**	**5**	**10**	**13**	**16**
Seed	1	2	3	4	5	10	13	16
Seed	1	2	3	4	0	0	0	0
Seed	1	2	0	4	0	0	0	0
Seed	1	0	0	0	0	0	0	0
Seed	1	0	0	0	0	0	0	0
Seed	1	0	0	0	0	0	0	0
Seed	1	0	0	0	0	0	0	0
Seed	1	0	0	0	0	0	0	0

To obtain the total seed count, the sum of all values in the grid was used to get the total number of seeds. The output is the total sum. Total number of seeds equals 76.

For the average density, the total number of seeds is divided by the total number of squares to get the average seed density per square. The average density equals 1.1875.

For the variance and standard deviation, it is calculated how much the number of seeds in each square deviates from the average density. The variance and standard deviation will show how evenly seeds are distributed cross the grid.

The formula to calculate variance is as follows:

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2 \tag{1}$$

where σ^2 is the variance, *N* the total number of regions or cells, μ is the average density (mean), x_i is the number of seeds in i-th region (the values in the table), $(x_i - \mu)^2$ is the squared difference between each seed count and the mean.

The variance of the seed density is approximately 8.53 seeds² per region.

The standard deviation is the square root of the variance.

$$\sigma = \sqrt{\sigma^2} \tag{2}$$

The standard deviation of the seed density is approximately 2.92 seeds per region. This gives a sense of how much the seed counts vary from the mean, on average.

To identify seed hotspots, a hotspot can be defined as a region where the number of seeds is significantly higher than the average density, where the seed count exceeds a certain threshold.

The hotspot threshold can be calculated and it can be noted as follows:

$$T_{hotspot} = \mu + \sigma \tag{3}$$

where $T_{hotspot}$ is the seed hotspot, μ is the average seed density and σ is the standard deviation.

In this case, the hotspot threshold will be 4.1075 which indicates that any region where the seed count exceeds would be classified as a hotspot.

For the Phacelia tanacetifolia seeds, the total seed count was calculated to be 99 seeds, representing the cumulative number of seeds distributed across all cells in the grid. The average seed density was found to be 0.538 seeds per cell, reflecting the mean seed distribution across the entire grid.

To assess the variability in seed distribution, the variance was calculated, yielding a value of 1.846, indicating a moderate spread of seed counts across the grid. The standard deviation, which measures the average deviation from the mean, was determined to be 1.359. This value provided insights into the clustering of seeds in specific regions of the grid.

Also, for the Lolium perenne seeds the total seed count was calculated to be 100, representing the cumulative number of seeds distributed across all cells in the grid. The average seed density was found to be 1.389 seeds per cell, reflecting the mean seed distribution across the entire grid.

To assess the variability in seed distribution, the variance was calculated, yielding a value of 10.599, indicating a moderate spread of seed counts across the grid. The standard deviation, which measures the average deviation from the mean, was determined to be 3.256. This value provided insights into the clustering of seeds in specific regions of the grid.

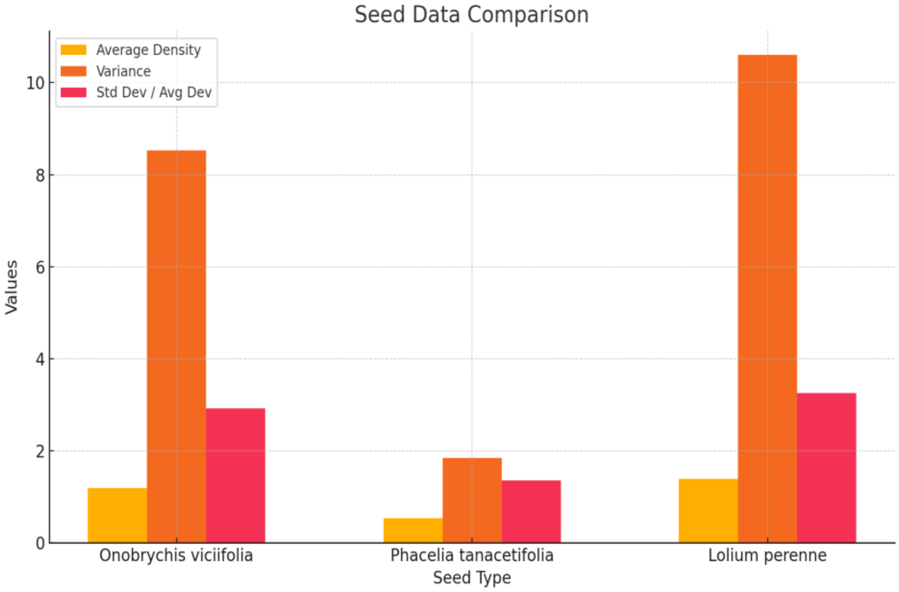


Fig. 14 – Seed Data Comparison

In Figure 14, the seed data comparison is presented. This comparison highlights the differences in statistical properties among the three seed types. The comparison of the three seed types—Onobrychis viciifolia, Phacelia tanacetifolia, and Lolium perenne reveals significant differences in their statistical properties. Onobrychis viciifolia and Lolium perenne exhibit similar average densities and standard deviations, but Lolium perenne has a slightly higher variance. Phacelia tanacetifolia, on the other hand, shows lower values across all metrics, indicating more consistent and less variable properties.

CONCLUSIONS

In conclusion, the adoption of EDEM by Altair Software is a transformative step toward enhancing the accuracy and efficiency of equipment design and material flow analysis. This advanced discrete element modeling tool allows for in-depth simulations of particle interactions and system behavior under a wide range of conditions, which is essential for predicting wear, optimizing processes, and reducing operational risks. By leveraging the powerful computational capabilities of EDEM, engineers can make informed decisions that improve performance and productivity before even conducting physical experiments.

However, while simulations offer a valuable preliminary understanding, their true value lies in their correlation with real-world outcomes. In the future, physical experiments will be conducted on the actual equipment, enabling a direct comparison between the simulation data and experimental results. This validation process is essential for assessing the software's reliability in predicting real-world scenarios and detecting any potential discrepancies. This hands-on approach aims to further refine the simulation models, ensuring they closely reflect real-world performance and strengthening confidence in EDEM's application for future projects. This integration of simulation and experimentation will be a key to advancing the accuracy and effectiveness of both equipment design and operational efficiency.

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