Parametric design and finite element analysis of a peanut harvester for saline-alkaline soil

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Abstract: This research addressed the problem of deep hard soil cropping areas because standard groundnut tools lack sufficient penetration to obtain satisfactory pod yields. An improved groundnut digger was designed to enhance harvesting capabilities in hard soil conditions. Tough soil breaks through two particular shares equipped with chisel points, which elevate peanuts toward the picking area at 110 degrees. The Yellow River Delta Intelligent Agricultural Machinery Equipment Industry Academy optimized the digging tool specifically for bunch-type groundnuts grown using 60-cm row placement in dry areas where soil conditions are normally hard. Analysis of structural performance was conducted through SPH method integration with LS-DYNA software to simulate ground-cutting procedures at a depth of 15 cm. During the test, the digger generated 737 N of force while the maximum steel material deflection was 1.48 mm, and peak stress reached 85.738 MPa alongside minimal strain of 0.0004. A high concentration of stress and strain originated from the blade tip. Soil-cutting operations remained stable under conditions where the stress reached 3.210 MPa and the force exceeded 650 N. Testing confirmed the tool could handle hard soiling conditions and presented acceptable financial terms. A promising tool for deep and hard soil peanut harvesting exists in the form of the YRDIA groundnut digger. Due to its advanced design, durable structure, and economical nature, this tool delivers significant benefits to improve pod harvesting efficiency in harsh agricultural environments.

Keywords: peanut digger, SolidWorks, ANSYS LS Dayna, saline-alkaline soil

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1 Introduction

People grow peanuts extensively because these plants bring both financial benefits and important nutrition to farm areas. The challenges of farming peanuts on heavy clay soil demand special farming methods for farmers to produce good harvests. This paper explains how farmers ought to cultivate peanuts in unfavorable clay soil and presents useful practices and valuable advice. China is the most active region in the production of peanuts, and recent statistics show that about 4.7 million hectares of peanut plantations are able to produce more than 18 million tons of products every year, which is a significant part of the world production (Gao et al., 2017).

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Nevertheless, farming under poor soil quality, especially in saline-alkaline areas, is a major challenge to achieving high yields and productivity (Qin et al., 2024). Recent developments have aimed at maximizing the geometry of the digging blades and material characteristics to minimize draft force and enhance soil penetration under hard soil conditions (Ling et al., 2024). Moreover, computational simulations, including finite element analysis, have become a critical part of the design and analysis of agricultural machinery, which allows for developing the cycles of work more efficiently and predicting the performance (Shen et al., 2023).

The peanut ranks as a top international agricultural export from China. China launched its peanut production machinery research and development project during the 1960s (Hu, 2011; Chen et al., 2020). The complete peanut mechanization process has made significant improvements over fifty years of work. Much of Dongying faces late-stage pod development droughts because soil moisture needs to be present for the groundnut harvest process. The majority of soil types, except sand, become excessively hard and hinder the harvesting process. Studies show our cutting tools cannot properly reach deep enough into hard soil to extract peanuts entirely, so the current farmers must improvise their blade mechanisms (Gobu et al., 2018). Chinese researchers have dedicated many years to peanut digging system projects and now hold valuable research findings. Zhang et al. (2022) developed Bio-tribological Characteristic of Peanut Harvesting Impact-Friction Contact under Different Conditions for analysis. Gao et al. (2022) studied the clamping and collecting arrangement of their three-ridge six-row peanut combine harvester to increase peanut collection efficiency in China. Chen et al. (2017) confirmed that harvesting forms the core of peanut production in their review. Although China and the United States are top peanut producers globally, the lower level of harvest mechanization in China creates its market edge. Shen et al. (2023) researched peanut digger-inverters as peanut harvesting tools across China and other nations. His findings help improve the peanut digger-inverter performance at harvest time and build hardware systems for peanut intelligent data collection. Literature reviews indicate that the adoption rate of peanut harvesting equipment in China remains lower than that in the United States, and peanut farming technology falls far behind expectations. In this paper, by systematic analysis on large number of literature and documents, the history of peanut harvest machinery in the USA was reviewed. The strategies that integrated machinery advantage into production practices through agronomic cultivation and breeding were summarized. It was also stated that the successful development experience of peanut harvest machinery in the USA will serve as a guideline for developing adoptable China's peanut harvest machines that are suitable for different cultivation practices, different peanut plants of botanical types, and different growing conditions such as soil types, growing seasons, and scales of peanut field (Gao et al., 2017). Zaied et al. (2014) performed a comprehensive development task for a motor-powered groundnut harvesting machine through design construction methodology. ANSYS 11 program ran computer simulations to determine the developed digger configuration. The machine operational evaluation took place through testing under conditions of sandy soil and clayey sand terrain. FEM simulation provided researchers with data concerning the impact of stress and deformation on moldboard surfaces. The simulation produced a maximum equivalent stress amounting to 279.43 MPa which exceeded the 250 MPa material strength value (Farid Eltom et al., 2015). The evaluation of dry soil tillage in sandy regions used the hypoplastic model as its assessment method. Research data showed that farm machinery productivity depends on blade design and soil selection parameters as well as their interaction with speed parameters and depth setting conditions (Abo-Elnor et al., 2004). The groundnut kernel provides 43-55% oil content with 25%-28% protein substance. The oil content in groundnuts consists of 22% linoleic acid with 61% oleic acid and high smoke resistance (USDA, 2010). The inefficient extraction of edible oil along with inadequate harvesting equipment and suitable technology have become important causes of lower productivity. The eventual production of oil is significantly impacted when fields suffer crop losses at the time of combining activities and extraction. The shortage of water functions as a cause for the low productivity of oilseeds. The extracted oil reaches yields that represent 15%-46% from the theoretical maximum output. Current production methods, seed quality deficiencies, limited water availability, poor harvesting methods, and extraction techniques restrict safflower, sunflower and canola crops from reaching their maximum yield potential (Ahmad, 2007). Research findings indicate the broad use of current semi-feed peanut combine harvesters but Chinese peanut combine harvesters require better adaptation alongside improved efficiency performance (Hu et al., 2010). The United States operates peanut digging and laying harvesters from KMC series and traction peanut combine harvesters from 9997 and 2110 according to AMADAS (2025). To advance peanut production industry both deep agricultural machinery technology and agrological practices need to integrate together. The research findings originate from peanut planting agronomy and plant biological characteristic investigations. The current research implemented ANSYS/LS-DYNA software simulation to study groundnut digger soil operations including blade penetration of soil and ditch formation. The Smoothed Particle Hydrodynamics (SPH) method performed the analysis through ANSYS/LS-DYNA software execution. This research evaluated how well the SPH method could simulate groundnut digger system soil cutting operations during excavation. The investigation focused on cutting force measurement in conjunction with power usage analysis to achieve the main research objective of Von Mises stress evaluation. The presented research model advances simulation methods to evaluate soil cutting system operation and mechanical behavior. The hardness of soils except sandy ones affects peanut harvesting procedures because soil moisture is insufficient for manual digging during drought conditions. The main goal of this research centers on the design and optimization of a groundnut digging system for hard soil to minimize draft force and plant clogging issues. The diggers operate as blade harrow variations through their differential blade dimensions and curvature shapes.

It is found that in recent years, new tendencies and local issues of harvesting technology have been observed in extensive areas of peanut cultivation. Namely, parametric design and cost-implication have also been reported in China with particular references to the machinery that is specially designed to work in saline-alkaline soils (Chang et al., 2024). European scientists investigated the correlation between the soil and the tools, as well as tool wear, which presents the productive opportunities of being cognizant of the optimization and durability of the blades (Refai et al., 2023). Likewise, the African studies focus on the context-specific issues, including the low-cost production of the smallholder farmers and arid climate adaptation (Zagre et al., 2024; Abass et al., 2014). The calculations have all been combined in the world with the help of computational methods, such as the finite element analysis (FEA) and the soil dynamics modeling, which now have given the opportunity to study the design as well as make forecasts of its functioning (Maraveas et al., 2025).

2 Materials and methods

2.1 Location

The Peanut Harvester Digging System was constructed in the saline–alkali agricultural experimental demonstration base in Huang triangle Agricultural High Zone, Dongying City, Shandong Province, China (geographical coordinates: 37.297° N, 118.648° E), and the soil pH value in this area was 8.3. The experiment, which was carried out from March to September of 2024, utilized particular agricultural techniques that would be used in saline-alkaline environments. There were 15 cm chisel ploughing done to create sufficient loosening to plant in hard and salty-alkali soil. The row spacing was 60 cm to ensure the growth of bunch-type groundnuts and to enable mechanical harvesting. The soil was sprayed every 14 days with drip irrigation to maintain soil moisture, which is essential for pod development due to the risk of potential droughts during late development. To boost crop nutrition, fertilization was done using NPK (15-15-15) at a rate of 50 kg ha^{-1} in the planting stage. The weed control was done by hand weeding, and the pests were controlled by using integrated pest management (IPM) in the presence of biopesticides to ensure that there was minimal impact of chemicals on the saline-alkaline environment. The soils of the Yellow River Delta (YRD) are saline-alkaline (PH 8.0-8.5), salty (2-10 dS m^{-1}), and silty clay loam (25-40 percentage sand, 40 percentage silt, 35 percentage clay) in texture. Peanut is not very fertile (high bulk density 1.3-1.5 g cm^{-3}) and it is difficult to harvest without special machinery.

2.2 Design description.

Figure 1 showcases the existing groundnut digging equipment of YRDIA. The groundnut digging system operates when the tractor provides power for the digging shovel to remove soil together with crops.

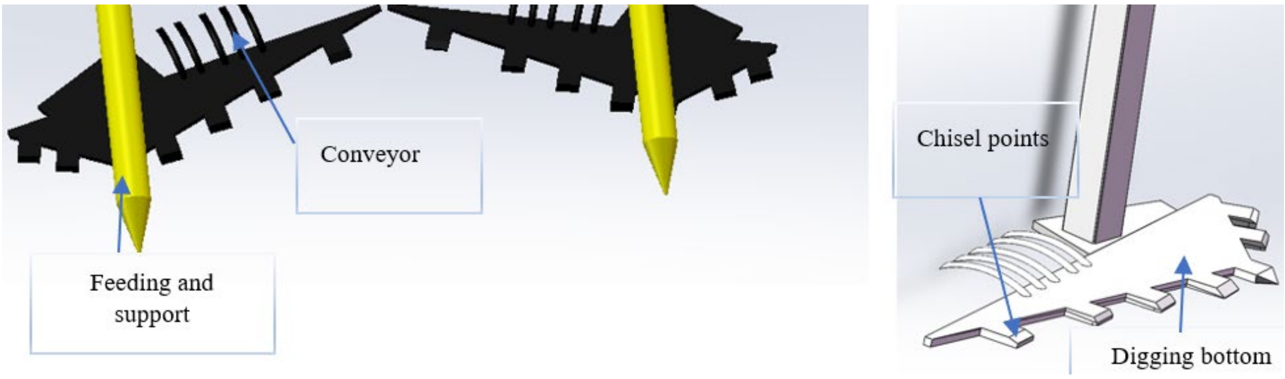


Figure 1 Existing YRDIA groundnut digging system

The digging shovel elevates crop and soil material using its chisel-point design. Predominantly the groundnut harvester machine serves to extract groundnuts from their growth spot. One operation permits this groundnut harvester to complete both digging and soil cleaning processes therefore it performs well in small groundnuts fields to reduce labor and boost operational efficiency. The groundnut digging system works best in hard soil conditions as well as hilly locations. The groundnut digging system has straightforward attachment capacity for other harvesting equipment systems while offering dependable operation. The first stage of research at YRDIA involved SOLIDWORKS software for modifying and enhancing different components of their groundnut-digging system. The second stage included testing system performance. The four fundamental elements of YRDIA groundnut digging machinery consist of the digger-bottom and chisel points, conveyor, and supporting bars.

2.3 Working principle

The tractor power take-off (PTO) shaft supplies the power for the machine. This operation is accomplished by a gear reducer and then to the clamping chain mechanism. The peanut support device first collects and directs peanut plants during the harvesting process for smooth and efficient peanut handling. In the center of the conveying chain, digging shovel is used to dig up the soil, and seedlings are clamped by the conveying chain and slowly lifted. Peanuts and soil are separated, and then the soil clods stuck on the peanuts are shook off by shaking the soil rod, and peanuts will be separated and thrown in the machine. The separated peanuts are thrown to the back of the machine and laid out neatly Figure 2. The ground wheel depth needs to be correct while the hand wheel operates at 780 mm above ground level as shown in Figure 2. Adjust the height with the bolt lock and tighten the nut afterward. Field and soil conditions have required designers to improve two essential points, namely the ground wheel design and the ground contact surface.

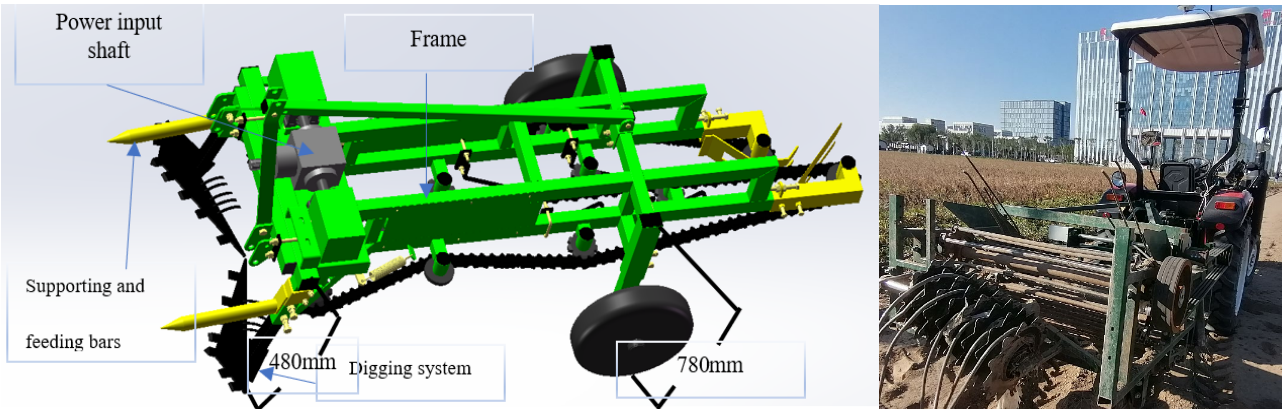


Figure 2 Schematic view of peanut harvester

Table 1 Technical specifications and characteristics of the new digging system

Characteristics	Description
Digger rake angle	110°
Digger length	480 mm
Digger base width	150 mm
Diameter of conveyer	500 mm
Diameter of the feeding and support cylinder	100 mm
Length of conveyor	500 mm
Length of feeding and support cylinder	315 mm
Digger Weight	12 kg

Table 2 Simulation parameters of saline alkaline soil and peanut digger shovel

Measurement Method	Parameter	Value
Hydrometer method (ASTM D792) for soil samples collected in March 2024	mass density, kg m^{-3}	2015
Calculated from bulk density and particle density via soil core sampling	Soil porosity (n, %)	36.5
Derived from material testing (ASTM E8) for carbon steel (EN8) and soil literature	Poisson ratio of blade (σ)	0.35
Determined using triaxial compression tests on soil samples	Bulk Modulus Pa	8.333E+7
Obtained from tensile testing (ASTM E8) of blade material	Modulus of Elasticity MPa	20
Measured using a tractor speedometer during field trials	Forward speed (v, m s^{-1})	0.10～0.15
Recorded with depth gauges during digger operation	Tillage depth (h, m)	0.15～0.20

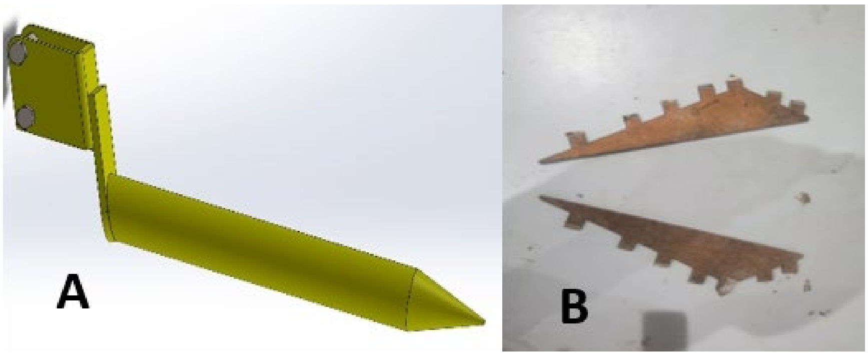
2.4 Design and construction

Soil working tool performance depends directly on its shape as well as movement orientation and the conditions of the initial soil. The tool width determines the direct proportion of horizontal and draft forces while operating depth results in exponential growth of these forces. Dry and brittle conditions created satisfactory soil shattering, and a 35° lift angle produced optimal results for shattering purposes. The vertical angle of the tool caused a reduction in draft forces until attaining a 40° setting. The cutting blades of root-cutting tools operate between 20° and 50° backward to gain better efficiency during cuts and automatically clean the blades while in use. A tillage tool can penetrate the soil based on its suction power. Root-cutting tools use cutting blades that cut at angles of 20° to 50°, as doing so allows the cutting blades to be more effective when performing cuts and also allows them to clean themselves during use (Liu et al., 2023). The penetration properties of a tillage tool are related to the suction force of the tool, which is determined by the angle of the shank of the tool against the soil. This may be modified by changing the position of the hitch point (Salar et al., 2013). The digger-bottom is constructed with several shares turned back 35°, or to make a 110° angle between them, the suction angle being 4.5°. Each of the five small chisels on board increases the penetration in the hard, saline-alkaline soils.

Based on varieties of soil, the SOLIDWORKS program was used, and a groundnut digger system was designed to meet the following functional requirements. The digger should cut the tap roots at the desired depth without dragging the plants and should loosen the soil sufficiently to permit lifting of plants, detaching a minimum number of pods. The digging system works well under soil conditions where blade-type diggers cannot penetrate adequately Figure 3. The digger-bottom has multiple shares that are swept back by 35° to make an angle of 110° with each other. The digger-bottom has a suction angle of 4.5°. Five small chisels are provided on each share to enhance penetration into hard soils. The chisels have a clearance angle of 13°, a lift angle of 19°, and a side angle of 35°. The chisel digger is shown in Figure 1. The digger-bottom components (including shares and chisels) are made of carbon steel (EN8) and heat-treated to Brinell Hardness Number (BHN) 401. Specifications of the digging system are given in Table 1. Table 2 shows the parameters of the saline alkaline soil and the peanut digger shovel used in the simulation.

There are two supporting bars on the digging system. The function of these bars is to convey the peanut leaves system. The clearance between the cutting blade and shovel points was not enough to convey thick crops. During the modification, the space was optimized. The cutting blade was notched and of Mult teeth shape. The modified blade was divided into two sharp blades with notches to improve the slicing of the hard soil.

The modified supporting bars in the groundnut digger are shown in Figure 3. The modified form of cutting blades in the digger is shown in Figure 3 B. The existing conveyor consisted of equally spaced bars, which did not provide any gripping arrangement for peanut plants for conveying purposes. A series of small pegs at alternate positions was provided on the conveyor Figure 3A. These pegs were welded on the conveyor to minimize the crop slippage.



(A) 3D CAD model of the modified conveyor (B) Modified fabricated cutting blade used in the experimental tests.

Figure 3 A series of small pegs at alternate positions

2.5 Analysis of the new digging system groundnut digger

Theory reveals the basic functioning principles of excavation procedures together with soil removal systems. The theoretical analysis needs additional intuitive visualization of movement phenomena to overcome theoretical method limitations. ANSYS Workbench 2025 was used to perform the static FEA that was used to analyze the structural performance of the groundnut-digging system. Boundary conditions were predetermined by having the two holes of the shovel as fixed and a load of working resistance of 737 N on the shovel surface. These values, which are much lower than the steel material stress threshold, verify that the structure is not going to collapse when it is under operational conditions, as in Figure 6. The major study goal focused on how the ground displacement and forces reacted to various loads applied to the excavating mechanism.

2.5.1 Meshing of the groundnut digger

Post-analysis processing depends heavily on the meshing operations of the newly built groundnut digger mining system. The process performs direct control over computational time and structural accuracy results. The meshing functionality within ANSYS Workbench helps engineers accomplish high-performance simulations through efficient precise meshing. One shovel in the mesh system incorporates 1,020 elements with 2,631 nodes to achieve precise analysis. A total of 13,351 discrete elements and 31,011 nodes during the overall meshing process enhance simulation results effectiveness as shown in Figure 4.

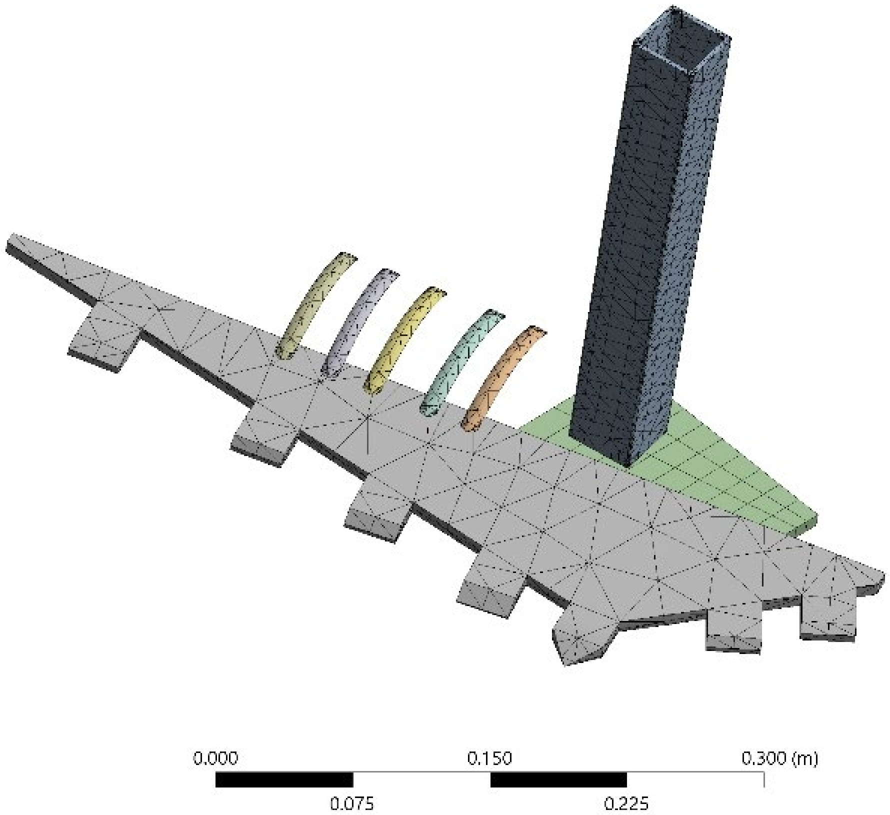


Figure 4 Meshing of the groundnut digger

2.5.2 Boundary soil of cutting process simulation

The soil cutting process comprises two distinct phases: the excavation process and the soil lifting process, which are determined by the cutting angle. The soil lifting process involves the (β) angle and the pull force (F), as illustrated in Figure 5a. Meanwhile, the excavation process is primarily influenced by the quality of the blade.

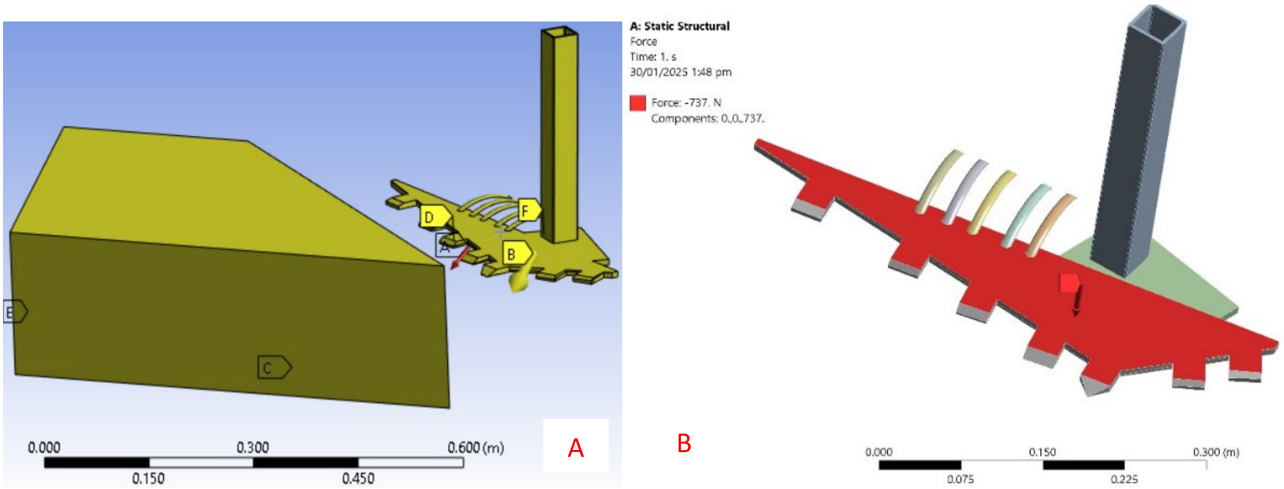


Figure 5 Soil-cutting process utilizing the groundnut digger's digging system

The initial design of the groundnut digger determines the rotational speed at 15 (v, m s^{-1}) while the simulation operates at 500 mm s^{-1}. During operation the groundnut digger blade experiences both static friction of 0.2 and dynamic friction at 0.18 between it and the soil. The LS PREPOST receives complete setups for boundary conditions as well as the solid material model and SPH soil model parameters. The parameters of boundary condition and solid material models and SPH soil model parameters are set to the LS-PrePost software on the groundnut digger simulation. It will generate a K file which will be processed by the solver LS-DYNA to simulate the excavation of soils (Qin et al., 2023; Agborambang et al., 2024). The statical and dynamic coefficient of friction between the blade and the soil is 0.2 and 0.18 respectively with the rotation speed and forward speed of the simulation having 15 m s^{-1} and 500 mm s^{-1} respectively.

3 Results and discussion

3.1 Application of constraints and load in the finite element model

Once the finite element model was established, constraints were applied to the shovel of the new groundnut digger system, and working resistance was imposed on its surface. Based on the actual installation conditions, fixed constraints were added to the two bolt holes at the rear end of the digger to ensure structural stability and accurate simulation Figure 5b.

3.1.1 Groundnut digging system static finite element analysis

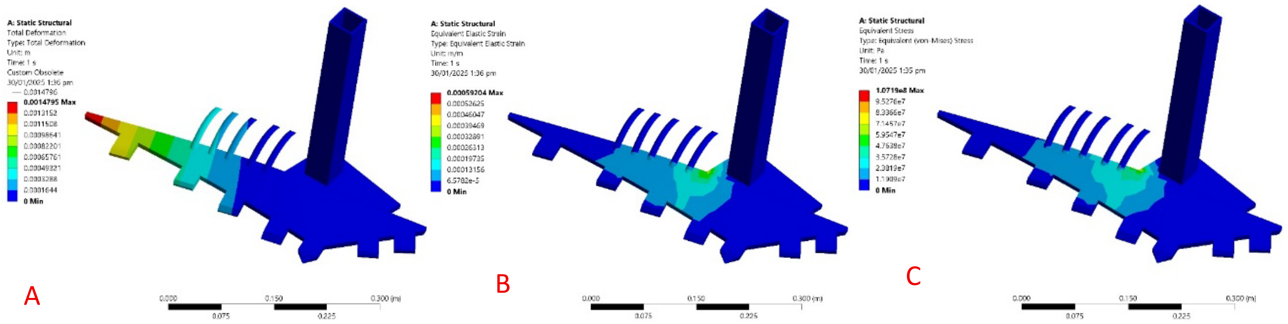
Through tractors, the groundnut digging system forces the digging shovel to uplift both the digging soil and planted crops. The complete system functions as a soil excavator, and the digging shovel handles crop and soil elevation with its equipped chisel points during operational phases. The combined resistance experienced by the whole excavation system substantially surpasses that of a single digging shovel. A thorough evaluation of stress, strain, total deformation, and displacement was performed through the utilization of both stress model findings and deep shovel experimental research (Issa et al., 2020). The resistance experienced by groundnut digging systems depends on four main variables: shovel width, digging depth, angle of shovel dip, and amount of soil displaced from the excavation point. The resistance in this system primarily depends on both the width and depth parameters. The research measured the working resistance of the digging system at 737 N.

The maximum deformation of the groundnut digging system was 1.48 mm.. Maximum strain measurements reached a value of only 0.0004, showing small degrees of deformation. Under working conditions, Figure 6 demonstrates that the maximum stress measurement of 85.738 Pa remained extremely lower than steel material stress thresholds to guarantee structural stability.

Results showed that stress reached its maximum value toward the blade's conclusion, while maximum strain appeared at the cutting edge of the spatula. Wider service life and durability of the digging system could be achieved through terminal section and blade tip reinforcement of hardness.

3.2 Groundnut digging system LS_DYNA finite element analysis

3.2.1 The von mises stress of the groundnut-digging system blade

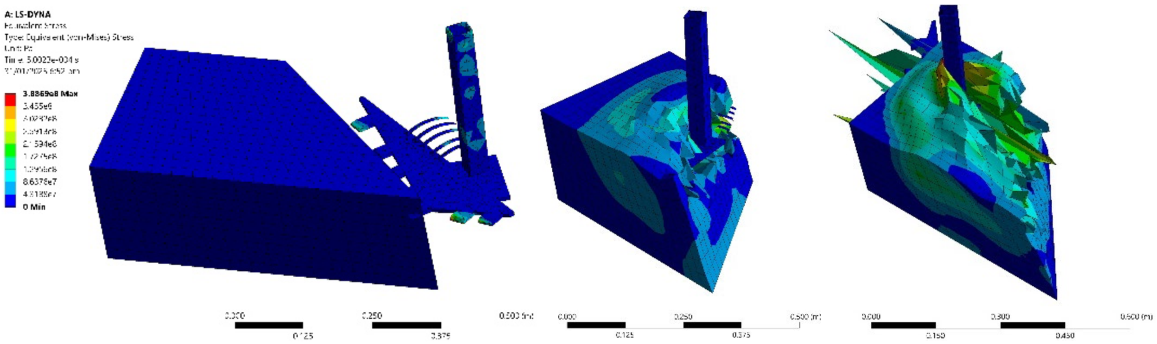


(a)Total deformation map (b) Equivalent strain diagram (c) Equivalent stress map

Figure 6 Groundnut digging system analysis

Figure 7 illustrates the von mises stress distribution in the soil at various stages as the peanut-digging blade penetrates the soil. Initially, when the digger blade is inserted into the soil, it does not contact the soil at its starting position (t=0.05 s, depicted in Figure 8a). Subsequently, the drilling system advances at speed V.

The peanut drill blade enters the soil surface at 0.5 seconds. Figure 7a represents the peanut digger blade, where the maximum von Mises stress achieves 2.7 MPa at 0.5 seconds. The pulling motion results in increased intensity of contact between the soil and the device. The peanut drill creates shear force along with compression that results in substantial increases in maximum von Mises stress levels in the material. The ongoing soil-cutting operation creates stable results that fulfill its operational requirements. The maximum von Mises stress in the soil develops when the peanut excavator blade enters the soil completely. The maximum von Mises stress in the soil ranges mainly from 3.210 MPa throughout the excavation period, reflecting minimal stress changes and an organized cutting process. The trench depth stays at 15 cm according to measurements. Through this arrangement, the excavator device can efficiently pull the soil up to approach the area where peanuts are picked. The blade maintains steady performance throughout its function in dry soil conditions.



(a)T = 0.5 s (b) T = 1.0 s (c) T = 1.5 s

Figure 7 Depicts the von mises stress distribution on the groundnut digger blade as it penetrates the soil during the cutting process

3.2.2 Cutting force during the process of cutting solid

Figure 8 illustrates the variation in cutting resistance over time during the soil-cutting process using the peanut digger blade. As evident from the figure, the cutting force gradually increases and stabilizes as time progresses. Between 0.5 and 1.5 seconds, the disc ditcher penetrates the soil, and the contact area between the peanut digger blade and the soil expands steadily. The maximum cutting force reaches approximately 700 N. The safety factor for each variant is calculated to be 15, demonstrating that the peanut digger blade's structure is highly secure and capable of withstanding loads of up to 700 N. For optimal performance, the steel construction blade model is recommended as the peanut digger blade.

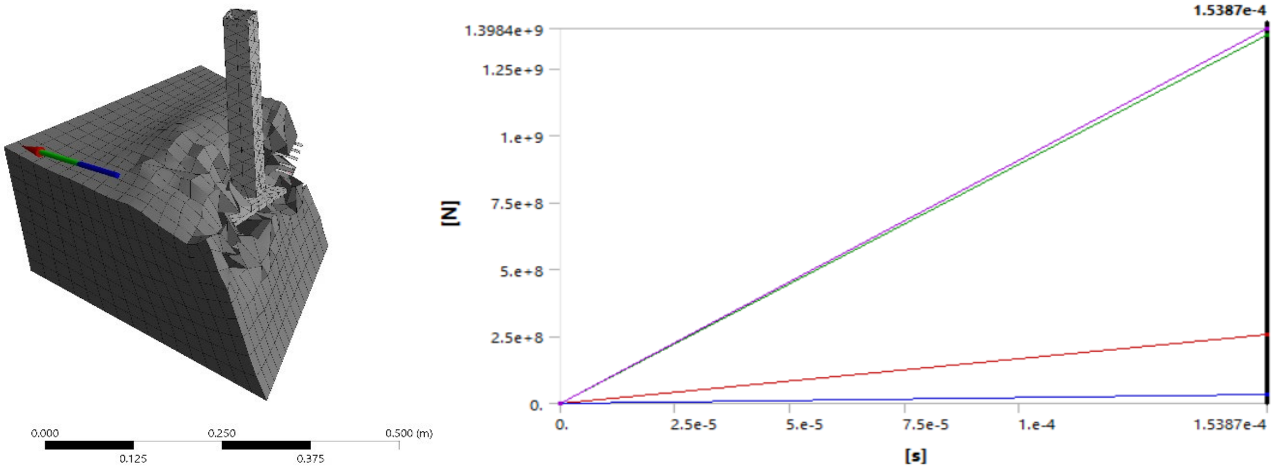


Figure 8 Cutting force during the peanut digger blade

The development of finite element models utilized the SPH (Smoothed Particle Hydrodynamics) method, which led to simulations executed within the LS-DYNA nonlinear transient dynamics finite element analysis software. Soil-cutting continues in an effective manner as the cutting procedure establishes stable variables throughout. The digger consistently cuts at a depth of 15 cm, but the maximum von Mises stress found in the soil stays primarily at 3.210 MPa. Throughout the blade infiltration into the soil, the cutting force shows a steady growth pattern from 500 N to 700 N before reaching a stable level of 650 N while digging. Parallel computing implementation leads to substantial decreases in computational expenses. A steel construction blade model provides the best performance outcomes when used as a digging blade. The lifetime of groundnut digging systems should be extended through reinforcement of hard areas at the critical stress points, including blade tips and terminal sections. The collected data leads to essential knowledge for optimizing the design while improving the operational efficiency of groundnut diggers under difficult soil environments.

4 Conclusion

To solve the problem of loss of pods due to stacking, throwing up, and the impact of peanut plants in hard and saline alkaline soils of the Yellow River Delta, a new groundnut digging system was invented. In this region, the harvesting of peanuts, especially the use of the picking machine, is of the essence to ensure that the mechanism of harvesting peanuts is efficient. Shovel finger and cylinder peanut-picking equipment, which was developed with the strip-picking behavior of creeping peanut plants, was found to perform better in the field. The creeping type is adapted to the new digit system as compared to the Chinese vertical peanut plants that bear poor quality and flexibility in adapting to the new system, as they form proper windrows. This system boosts efficiency in harvesting in demanding soil conditions, as confirmed by the field results and finite element analysis.

The new peanut digging system has a high level of efficiency in peanut harvesting in the saline-alkaline silty clay loam soils of the Yellow River Delta. ANSYS/LS-DYNA showed a maximum deformation of 1.48 mm, strain of 0.0004, and stress of 85.738 Pa, which is significantly below the threshold of the steel, and therefore proved the structure to be stable at a load of 737 N. The chisel-point blades of the system were angled to 35° with a 110°C configuration, which, in combination with the stacking and impact, minimized pod loss, providing stable soil-cutting at 15 cm depth and a 3.210 Mpa von Mises stress. The suggested enhancements are strengthening the blade tips to increase their lifespan, precision irrigation to maximize soil moisture, sensor-based monitoring to determine real-time blade performance, and lightweight material to minimize energy use. The improved technologies will offer a viable long-term solution to machine harvesting of peanuts in problematic soils, and it can ultimately be extended to other agroecological regions.

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