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RESEARCH ARTICLE – MECHANICAL ENGINEERING

Using Different Angles of Rotating Blades Using the Finite Element Method

Hassan Ali Hassan[1], Ahmad Soheili Mehdizadeh[1*]

[1]Department of Mechanical Engineering, Kermanshah Branch, Islamic Azad University, Kermanshah, Islamic Republic of Iran

[*] Corresponding author E-mail: Ah.Soheili@iau.ac.ir

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Abstract

One of the most important operations in agriculture is tillage, which has a great contribution to increasing crop yield and aeration of the soil and, ultimately, root development. Among the important tools for tillage are rotary rotators that are exposed to high and variable dynamic loads, so they are designed to have both the greatest contribution to soil agitation and high strength; It is necessary. Therefore, in this research, an L-shaped blade sample was designed for a rotator using a Biomimetic method. Due to the extensive research that has been conducted globally in the field of manufacturing different types of rotators with a rotating agitator mechanism, it is necessary to study and optimize the rotator blades according to Iranian conditions. In this study, the studied variables include dependent and independent variables. Dependent variables include von Mises stress and arm displacement, and independent variables include the dimensions and geometric parameters of the Shape of the Rotator Blades. The idea for the blade design was inspired by the paw of a mole rat. Six blades were designed by simple method and biomimetic method and then by finite element method. The effects of blade angle change and design method on stress distribution, maximum displacement, maximum energy absorbed in the blade, reliability, and performance under 400 N were evaluated. The results showed that in all designed models, the values of stress, displacement, and energy absorbed were lower in the biomimetic design mode. As the blade angle increased, the values of the above parameters also decreased. Finally, the best model, with the least von Mises stress and highest reliability, was the blade with a biomimetic design and a 20-degree angle.

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1. Introduction

A rotator is one of the agricultural machines, which is used for primary and secondary tillage operations in agricultural fields. The function of this device is to invert the soil and provide a suitable environment for planting crops. During this process, the rotator increases soil porosity and aeration, which in turn improves germination and crop growth. One of the advantages of the rotator over other devices that perform the same operation is the creation of a forward force that reduces the need for tractor traction [1,2]. Compared to conventional plowing machines and tillage methods, the total power required by the rotator is less, and the machine is more efficient in the direct transfer of engine power to the soil. Compared to the tillage rotator, the power consumption of the rotary type is 25% less [3,4]. Typically, the power generated by the engine is fed to the rotator by the tractor's PTO rod. The rotational motion generated is then transmitted to the rotor via the gearbox and transmission system. Flanges are also installed in the rotor, to which the cutting blades are attached. The purpose of this study is to investigate the various forces and stresses applied to the rotor axis of a typical rotator affected by transient loads [5,6]. Conventional rotator models were considered for study and analysis due to their progressive cutting sequence. Research has expanded to look at several other models, each with its cutting blade layout. This research has identified the various forces applied to the rotor axis of a rotator, as explored in other studies. The location of the torque and the forces applied vary depending on the model. The solution was obtained by considering the angle of torsion and the equivalent stress applied to the rotor shaft [7,8].

The continuous increase in the price of fossil fuels has led to a significant increase in the cost of preparing agricultural land. This has a direct impact on food prices, which in turn leads to a significant increase in costs. This situation is exacerbated by the widespread use of traditional tillage operations in seed field preparation, particularly deep tillage [9,10]. This tillage system increases the cost of land preparation because it requires a series of operations using inactive tillage tools to achieve an acceptable quality of cultivation. This also ties up capital in other machinery and tillage tools, leading to a significant increase in the cost of land preparation. A rolling tillage machine is the most suitable tillage machine for preparing seed fields [11,12].

3D modeling and the finite element method have become an engineering tool used all over the world. Examples of the application of three-dimensional modeling and finite elements can be found in various fields of engineering. Insufficient technical knowledge, incorrect use of new technology, and unseen defects in the characteristics of a new design, especially in the small and medium-sized agricultural machinery industries, can cause problems such as breakage and failure. When conducting field operations [13].

Nomenclature & Symbols			
N	Newton	MPa	Megapascal
Hp	Horsepower	FEA	Finite Element Analysis
FDM	Finite Difference Method	BEM	Boundary Component Method

This study aimed to design an L-shaped blade sample for a rotator using a biomimetic method. The idea for the blade design was inspired by the paw of a mole rat. Six blades were designed using the simple method, the biomimetic method, and then analyzed by the finite element method. Effects of blade angle change and design method on stress distribution, maximum displacement, maximum energy absorbed in the blade, and reliability under 400 N were evaluated. The results showed that in all designed models, the values of stress, displacement, and energy absorbed were lower in the biomimetic design mode. As the blade angle increased, the values of the above parameters also decreased. Finally, the best model for having the least von Mises stress and the highest reliability was the blade with a biomimetic design and a 20-degree angle.

The main contributions of this research are:

- Rotators, meanwhile, have gained attention due to their special features and widespread applications, such as working in gardens and under trees, as well as greenhouses and green spaces. A rotator as a protective tillage tool also helps manage crop residues. Due to the extensive research that has been done in the world in the field of manufacturing different types of rotators with a rotating agitator mechanism, it is necessary to study and optimize the rotator blades according to Iranian conditions.
- In this study, the studied variables include dependent and independent variables. Dependent variables include von Mises stress and arm displacement, and independent variables include the dimensions and geometric parameters of the Shape of the Rotator Blades.

The main objective of this research is to design new rotator blades to withstand more load and stress than the current arm of the tractor under study.

Other sub-objectives are

- Finding effective parameters in stress distribution in the Rotator Blades.
- Stress analysis in different designed models
- Design a new model to withstand more load
- The bio-imitation method is effective in optimizing agricultural implements.
- Optimize the rotator blades using the bio-emulator method.

The organization of this manuscript is as follows: Section 2 discusses the recent research, Section 3 discusses the engineering problems solved, Section 4 discusses the results analysis, and Section 5 describes the conclusions.

2. Related Work

There are various definitions for tillage. But in the practical sense, tillage means changing the physical properties of the soil to create favorable environmental conditions for seed germination, emergence, and plant growth and development. This operation is performed with different tools and in different ways such as cutting, spreading, turning or mixing the soil in one or more steps [14].

The main purpose of tillage operations is to increase production and maintain existing resources and potentials. But some farmers do this for other purposes, including [15]: burying plant debris under the soil, Preparing the substrate for planting and seed germination, weed control, Breaking the soil, maintaining soil moisture, increasing soil permeability in soil, Mix fertilizer with soil.

Tillage is divided according to the amount of soil mixing and upside-down during operation. Primary tillage usually returns topsoil and most crop residues. Primary tillage is often the first operation conducted after harvest. Secondary tillage machines mix a small amount of soil and plant debris with the soil and bury it. For many good and logical reasons, we cultivate in arable lands, while on the other hand, it may also have negative effects. If the soil surface is not empty and covered, it is a very good factor for wind and water erosion. Erosion is an important issue because we lose the fertile soil, the surface that is composed of organic and nutrients, and this reduces soil fertility. Turns. Management methods to control erosion can be effective. In a new management system, light and insignificant tillage is used as well as leaving plant residues on the soil surface. In recent years, most farmers have used this method without tillage, crop residue management system, soil conservation, and tillage [16].

The purpose of this operation is to prepare the initial structure of the soil and disrupt the cohesion between the soil particles. This action is to better ventilate the soil and increase the ability of water to sink into the soil. The most important primary tillage operation is plowing. This is done by special machines and machines. In the past, plowing, a type of livestock tool, was used to plow the land. But today, with human progress, new tools and devices have been introduced to the market that facilitate these operations [16]. This type of plow was used in Europe and other parts of the world. These types of plows bury 90 to 95% of crop residues in each series of operations, and only 5 to 10% of the residues and topsoil are not removed [17].

These plows are used all over the United States and return 80 to 90 percent of the crop residue, leaving only 10 to 20 percent of the residue at the soil surface. In the following conditions, plate plows perform better than reversible plows [17]: For deep plowing, in heavy and sticky soils where the soil is cut better due to the rotation of the plates, in light and sandy soils where it is difficult to return the soil, in dry and hard soils where reversible plows cannot penetrate, In rocky areas or areas with roots of plants and trees.

These types of plows bury 70% of the debris gently and leave the rest on the soil surface, and the distance between the chisels and the speed of the tractor determines the amount of work done. The plow does not turn the soil in any way, but only crushes the soil after penetrating it. This plow is very effective in maintaining soil moisture, so it is recommended for rainfed areas [18].

Due to the continuous movement of heavy machinery in the field, the presence of various salts in the irrigation water and the natural conditions of the soil gradually form a layer under the soil. This layer is called the Hard Pan. To break this layer, a machine called a breaker is used. These types of plows are used to break up hard and underground soils to improve water penetration and root expansion, and usually 90% of crop residues remain on the soil surface [19].

The rotary plow is one of the agricultural machines that perform primary and secondary tillage to prepare the seedbed. The uses of a rotary plow are as follows [20]: This plow can be used for weeding and breaking soil. It is used for mixing fertilizers and chemicals with soil, crushing and mixing plant debris with soil, digging up weeds, and destroying rat nests in orchards.

Bio-imitation or bio-simulation is the imitation of patterns, systems, and elements of nature to solve complex human problems. The basis of this science is natural biological models; by studying their physiology, you can design and build new technological systems. Structures and materials, which have proper adaptations in living organisms, have evolved through natural selection. Bioscience has led to the creation of new technologies inspired by biological solutions at large and nanoscale. Humans look to nature for inspiration to solve their problems. Nature has solved engineering problems such as repair capabilities, tolerance in various environments, hydrophobicity, and utilization of solar energy [21].

Today, all human inventions can be considered as a kind of use of living models. Assistant computers and robots that have gradually replaced humans have been built based on the study of biological structures. Aircraft designs based on the body structure of birds, the construction of submarines based on the structure of dolphins, and the construction of radars based on the bat radar system are examples of biometric or bionic science [21].

One of the first examples of bio-imitation was the study of birds to create the ability to fly in humans. Leonardo da Vinci (1452–1519), although never successful in inventing "the flying machine", was a shrewd observer of the anatomy and flight of birds and made numerous notes and sketches of his observations, as well as sketches of the "flying machine". Had made. The first aircraft built by the Wright brothers was inspired by observations of pigeons in flight. The science of bio-imitation was invented by the American physicist and scientist Otto Smith in the 1950s while studying squid nerves, and the term bio-imitation entered the dictionary in 1974 [16].

A process of cellulose self-regulation inspired by a special berry is used to make optical films. These films are made from cellulose, which is obtained from wood or cotton. Structural paints are more durable and vibrant than paints obtained by chemical absorption of light. This pigmentation is also seen in other types of berries. These fruits show a glowing color in the green-blue area of the visual spectrum, which gives them a shiny appearance. Structural colors are obtained by organizing cellulose chains on the outside of the fruit, part of the fruit skin. Each extracellular cell is composed of several layers of loops that act as a reflector [22].

Bio-immunity will be used in many fields in the future. Due to the complexity of biological systems, a large number of parameters may be mimicked. Applications of biomimetics at various stages of development range from commercially capable technologies to prototype models and prototypes. Inspired by the structure of the African termite mound, for example, researchers were able to design a building that uses only 10 percent of the usual energy to properly ventilate and keep the building cool. Seashells stay attached to the sea beds during tides, using proteins in their filament-like legs. These proteins contain a special combination of different amino acids that are adapted for adhesion. By identifying and using these proteins, engineers will be able to produce waterproof adhesives. Engineers are also considering using spider silk to design parachutes, suspension cables and artificial ligaments for medical use. Other research has focused on the production of leaf-inspired solar cells, the production of clones made of shark skin, and the extraction of water from fog like a beetle [22].

The purpose of using modern farming systems is to save energy and reduce agricultural costs. The optimal design of agricultural machinery should be proportionate to the current power of the tractor to achieve this goal. In this study, finite element analysis of the cultivator satori blade was performed using Solid Works and ANSYS software. The three-dimensional blade model was prepared using SolidWorks software, and the analysis of static blade structures was performed using ANSYS software. The material and dimensions of the satori blade were selected according to Indian standard IS: 6690-1981. The simulation results showed that the maximum deformation of 4.14 mm for the blade was observed under the given boundary conditions, while the maximum equivalent stress (von Mises) was 654.25 MPa. The maximum main stress and maximum shear stress in the stature blade were 656.26 MPa and 327.60 MPa, respectively. The reliability value was 1.05, and it was found that this value is very low. Apparently, this value decreases under unwanted crop loading conditions, and therefore, the blade does not meet safe conditions [23].

[24] designed rolling tillage tools such as rotary machines using computer software. The interaction of rotational motion and soil surface was investigated according to soil dynamics against the tillage machine by considering factors such as tractor power (hp), maximum lateral force (N), cultivator gear speed (m/s), tractor power transmission efficiency (0.9 for simultaneous rotation and 0.8-0.9 for reverse rotation), soil resistance up to 0.7-0.8, and rotation radius (mm) affecting tillage operations. This design was analyzed [24].

- Maximum lateral force on the rotating blade 6031.08975 N (for 35 hp) and 7041.17 N (for 45 hp)
- Torque = 270600 N-mm (for 35 hp) and 315920 N-mm (Appendix I).
- The results of analyzing the design of the cultivator machine, along with the simulation file, were obtained regarding the yield stress and deformation resulting from field conditions in the post-processor.

This project aims to design and optimize the cultivator machine blade to have a better service life and better performance in the field. Hence, any improvement in farm performance in turn strengthens and increases productivity in the agricultural sector. The design and modeling of the rotor assembly have been done. Dynamic analysis of rotator blades during tillage operations is performed using the Abaqus FEA tool. Complete three-dimensional modeling of a model of cultivator blade with 45 hp has been done using CREO PARAMETRIC 2.0 software. The kinematics of the blade motion were investigated, and the path traveled by each point on the blade tip was calculated and plotted. Blade characteristics such as bite length, kinematic parameters, and placement angle were investigated. Dynamic analysis of cultivator blades during tillage operations is performed using Abaqus FEA tool software. The simulation work helped to understand the nature of the cut created by the blade on the farmland. It was found that the deformation of each blade is the minimum value when the blade angle increases to 105. Using the method followed in this analysis, understanding the nature of the cut using alternating blade shapes needs to be investigated, and the volumetric component of the cut soil should be compared with the volume of uncut soil to obtain the optimal blade profile for tillage.

In [25], they identified and addressed problems with rotator blades. Cast iron is the standard material used in the manufacture of blades, and these materials create high stress. In this project, different compositions and dimensions of materials were considered for analysis, and loading conditions were applied to existing and modified blades. The best composition and dimensions of the materials are suggested. By changing the design of the cultivator blade, the working hours of the blades can be increased, and their wear resistance can be increased by using different materials.

Rotator blades are one of the most important parts of a tillage machine that engage the soil to prepare the ground. These blades interact with soil in different ways compared to ordinary plows. This causes the blades to be subjected to severe impact and friction, which in turn causes an imbalance and the application of the same forces on the rolling mower, causing the blades to wear out. The continuous oscillating effects of crust/clods / soil rocks cause high-stress areas on the blade tips or important blade edges. Therefore, it is necessary to optimize the blade design so that these blades can withstand more stress (Fig. 1). This paper seeks to optimize the design of rolling mill blades using modern tools such as finite element analysis [6].

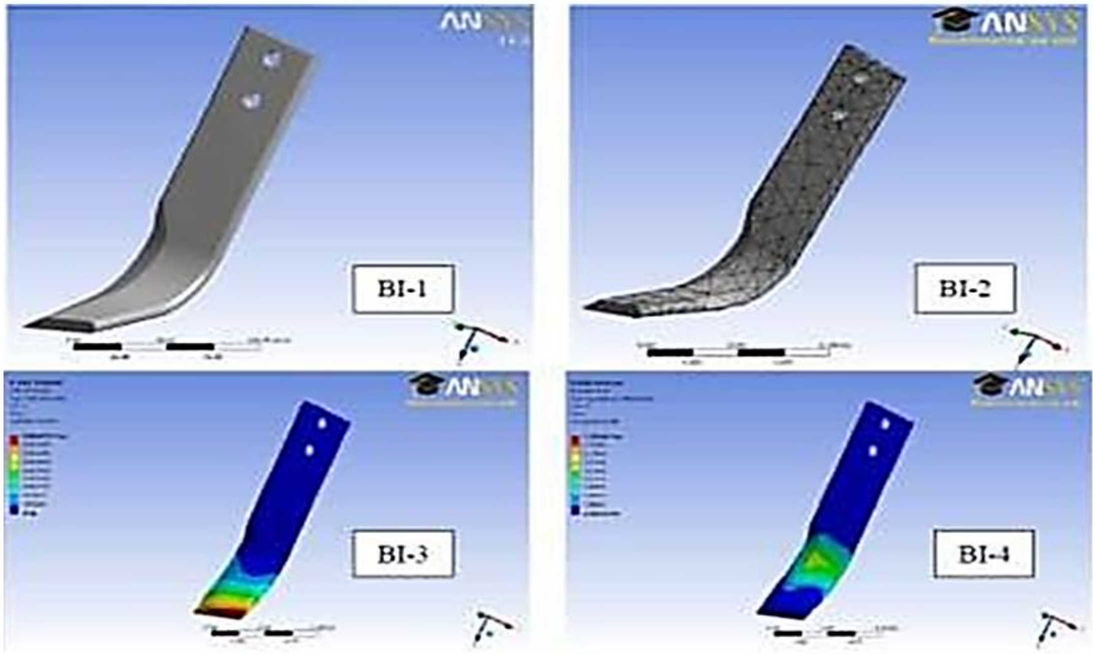


Fig. 1. Blade analysis results (BI-1: 3D model, Bi-2: Meshing, BI-3: Deformation and BI-4: Von mises stress) [6]

Fine-grained clay is the predominant soil in Asian rice fields that is left barren or cultivated with crops other than rice after the monsoon harvest. However, the use of seeders by the principles of conservation agriculture in such soils has not been promising. In such a situation, which prevails in the densely populated and poor areas of the coasts of South Asia, these machines cannot plow the land or cause a lot of soil to be thrown from the furrows during strip sowing. This leads to poor seed coverage at planting and thus jeopardizes crop establishment. In response, in the study of laboratory soil reservoirs, the designs and settings of strip tillage blades to optimize the strip rolling system for wet clay soil conditions that are common in South Asian rice fields have been investigated. Three designs of rotating blade type C (traditional, intermediate, and direct) and two modes of blade settings (four and six blades in a row, cutting width 50 and 100 mm) for three depths (50, 75, and 100 mm) and creating a seedbed in Plow furrows were tested. This was done using tillage testing equipment, a laboratory soil tank, and a high-speed camera to understand the processes of soil cutting, soil throwing, tillage, and creating a plowed bed for seeds. The laboratory reservoir soil consisted of loamy clay-wet sand soil with a moisture content of 28.2% (85% of field capacity) and was compacted to a density of 1440 Kg / m^3. Using the test equipment, the blade rotation speed was maintained at 480 rpm, and the advance speed was maintained at 0.4 m / s. In the case where four blades were used in each row, all the blades created large optimal clumps (1-20 mm in size).

Traditional blades and interfaces had thrown large amounts of soil through the grooves created by the strip method, but the use of a straight blade had created sufficient embankments at depths of 75 and 100 mm. In the case of six blades in a row, the blades created a large amount of debris at each depth, but the straight blade also produced the most optimal lumps and uniform grooves. Considering the cost of machinery and energy, blade performance, and the need to minimize soil disturbances in strip tillage, our study shows that the use of straight blades (four blades in a row) that worked at a depth of 75 or 100 mm, it is more ideal (Fig. 2). These characteristics probably strengthen the establishment of the strip tillage system jack in fine-textured soils with high moisture content. However, verifying the stability of the strip tillage system requires more work to establish crops in newly barren lands as well as in Asia under intensive cultivation [26].

Designed central gearbox, side gear, shaft assembly, shaft between four-wheel drive and upper side gear, and main chassis were validated by ANSYS R15.0 WORKBENCH software analysis of static structures (Fig. 3). The developed tool was tested with high accuracy in the workplace and had a successful performance up to a depth of 14 cm and a forward speed of 7 km / h in sandy loam soil with an average moisture content of 12 ± 0.75% (db). It was found that field capacity, farm efficiency, and fuel consumption during the first stage of the crossing with a forward speed of 3.69-6.55 km/h and an average working depth of 12 cm were 0.37-0.57 ha/h, 71.23-81.35%, and 4.95-6.42 L/h, respectively. Finite element analysis (FEM) allows the optimization and simulation of complex agricultural machinery and the study of stresses and deformation of parts just before the development of machinery to prevent errors and failures in the next phase of field evaluation [27].

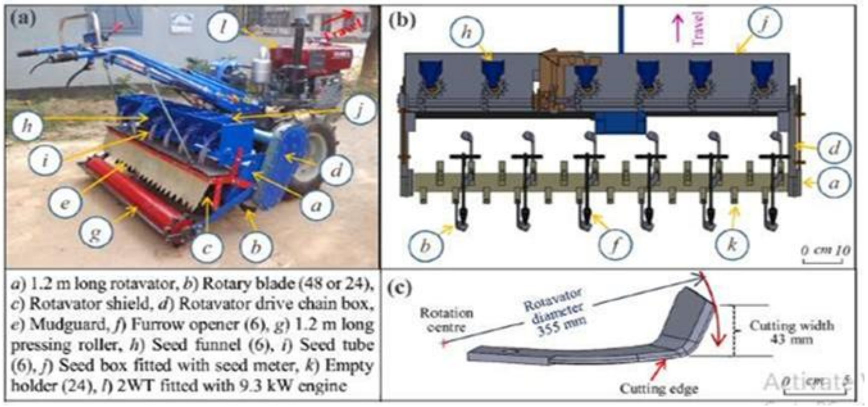


Fig. 2. (a) 9.3 kW two-wheeled tractor equipped with a six-row rotary seeder (1.2 m wide cultivator equipped with 48 blades), (b) modified strip configuration of the blades on the 1.2 m wide cultivator (All four blades are open and therefore there are 4 blades in each row and six rows), and (c) bent blade type C (holder on the right) (traditional blade) used in rotary seeding [26]

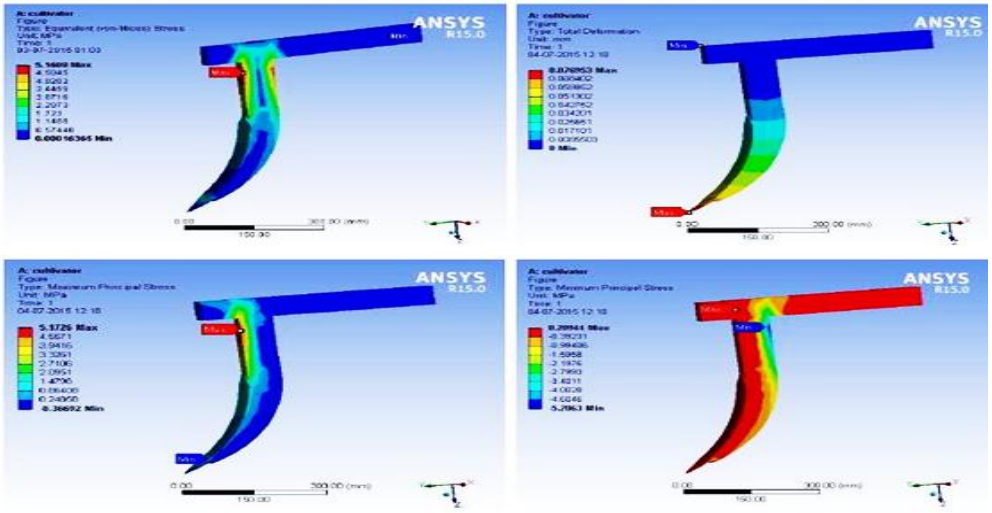


Fig. 3. Results of main chassis finite element analysis [27]

In [28], the finite element analysis of a nine-branch cultivator machine is presented. A cultivator is an important agricultural machine used in land preparation. The main purpose of this analysis is to identify errors and failures in the shovel due to varying loading conditions at different speeds and in intermediate black soil.

Existing cultivator machines produced by local manufacturers tend to fail after approximately one season. The CAD model of the rake was created using CREO-parametric software, and then, using ANSYS software, finite element analysis was performed to determine the stresses (Fig. 4). The maximum and minimum main stresses were 5.1726 MPa and 0.20944 MPa, respectively, with a total change of 0.076953 mm. The maximum amount of stress did not exceed the yield point because deformation does not cause failure in the rake [28].

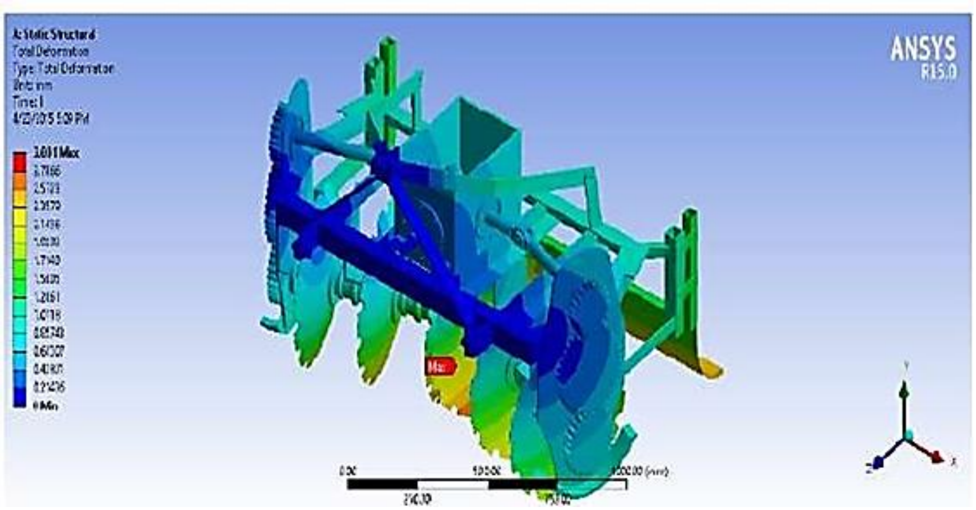


Fig. 4. Results of cultivator stem modeling [29]

The bio-imitation method involved designing two new blades (water-repellent blade and locust) to reduce the energy required to cut crop stems. They compared the energy required to cut two groups of forage plants using the new blades and conventional blades (smooth and curved). According to the results of the present study, a significant difference was observed in the shear energy of bio-imitation blades made in all treatments compared to conventional blades (smooth and curved). Abzdak's biodegradable blade reduced the energy required to cut plant stems by an average of 39.13% compared to flat blades and 32.8% compared to curved blades (Fig. 5) [29].

Fig. 5. Biomimetic blade (right) of Abzdak and (left) of locusts [29]

3. Solve Engineering Problem

The following three methods can be used to solve engineering problems in general:

- Analytical method
- Experimental method
- Numerical method

There is no analytical solution for many engineering problems that have complex geometry or loading conditions, so the analytical method is very limited, which reduces its scope of application, and experimental methods are also very expensive. However, problems with complex geometry and loading can be analyzed by numerical solution methods. There are several methods of numerical solution, but the most popular are:

- FDM - finite difference method
- BEM - boundary element method

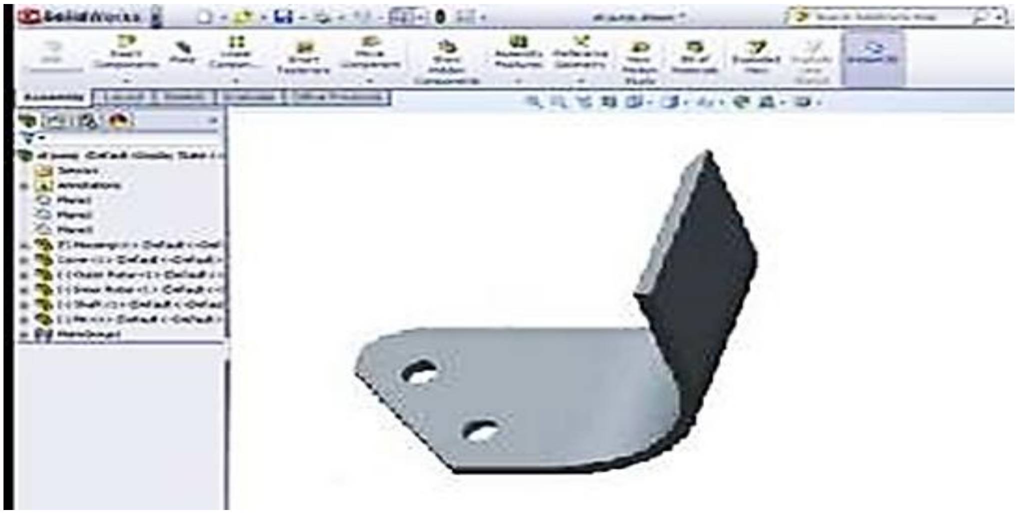


Fig. 6. An example of a blade designed in a Solidwork environment

In this research, the finite element method was used to investigate the forces acting on the blade and its deformation. Then, for the analysis and engineering of the blades, Abaqus software was used to study the displacement and stress analysis in the blade. The name abacus is derived from the word abacus, meaning abacus, and the Greek word abax, meaning covered with sand. The software was developed by completing research at Brown University in Providence, Rhode Island.

3.1. Specifications of the designed blade

First, a simple rotator blade was designed with the specifications presented in Table 1. The designed example is shown in Fig. 7. In Table 1 and Fig. 7, all the parameters shown are fixed during the design and only the bending angle of the blade was considered as a variable. Three values of 20, 25 and 30 degrees were considered for this parameter, and simple blades were designed based on these specifications.

Table 1. Specifications of the blade under study

Amount	Unit	--	Variable
40	mm	w	Width Blade
212	mm	Lv	Vertical Length Effective
88/7	mm	Lh	Width of cutting Blade
40	mm	R	Lv Lh
108	degree	θ	The curve angle of the blade
8	degree	β	Behind angle
30,25,20	degree	ε	bending angle

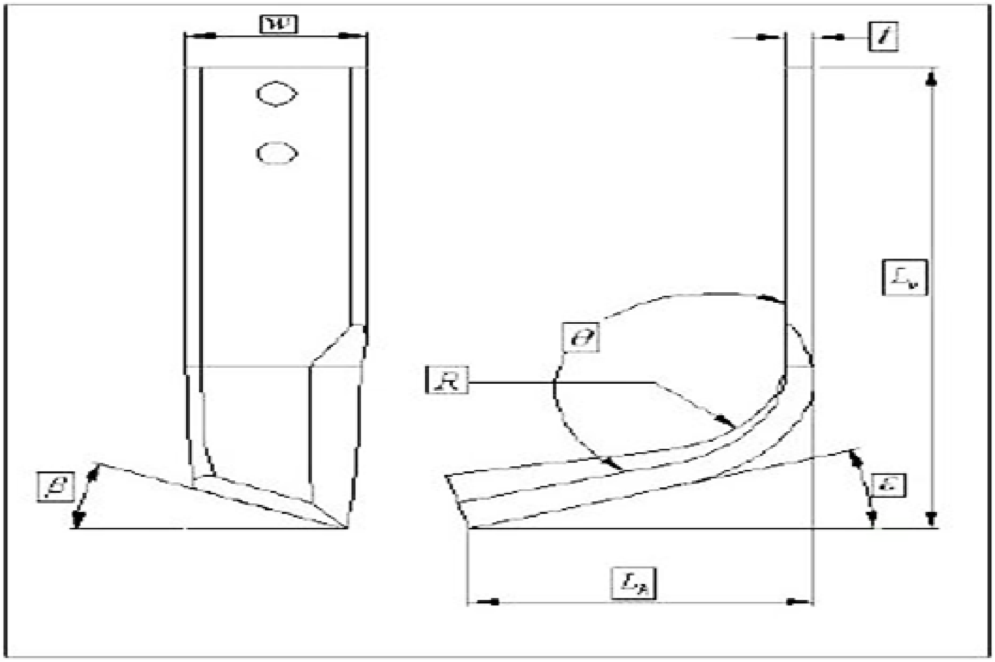
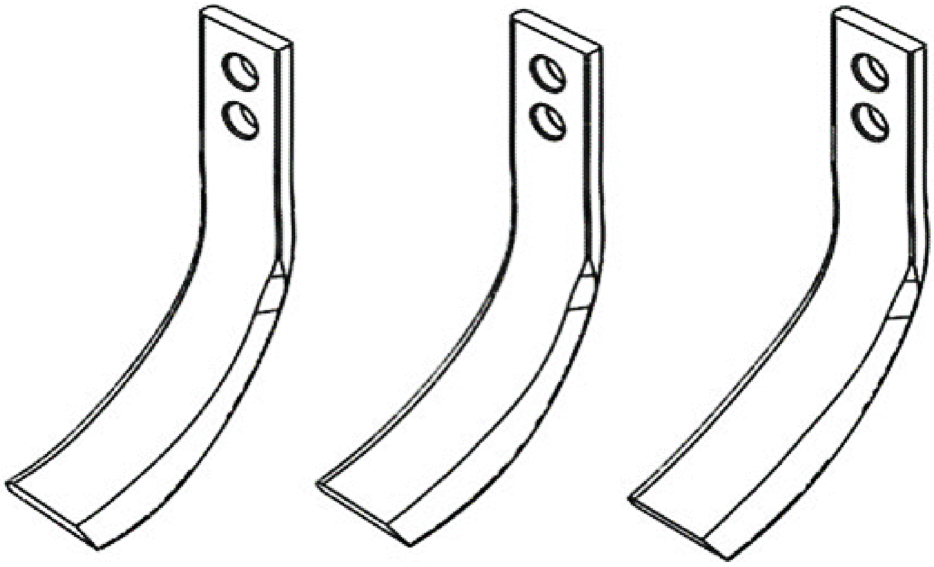


Fig. 7. Schematic of the designed blade

Fig. 8 shows all three examples of simple and common blades used in rotary rotators. It should be noted that in all different models designed, the blade sharpening angle was considered equal to 30 degrees.



20 degrees 25 degrees 30 degrees

Fig. 8. Designed blades with a simple and common structure

3.2. Geometric features of blades designed

The paw model was designed based on image-to-element conversion in SolidWorks software. Based on the specifications presented in Table 1, three new models of rotator blades were designed with the same information but with a structure using a mole rat's paw. Fig. 9 shows the models of this blade.

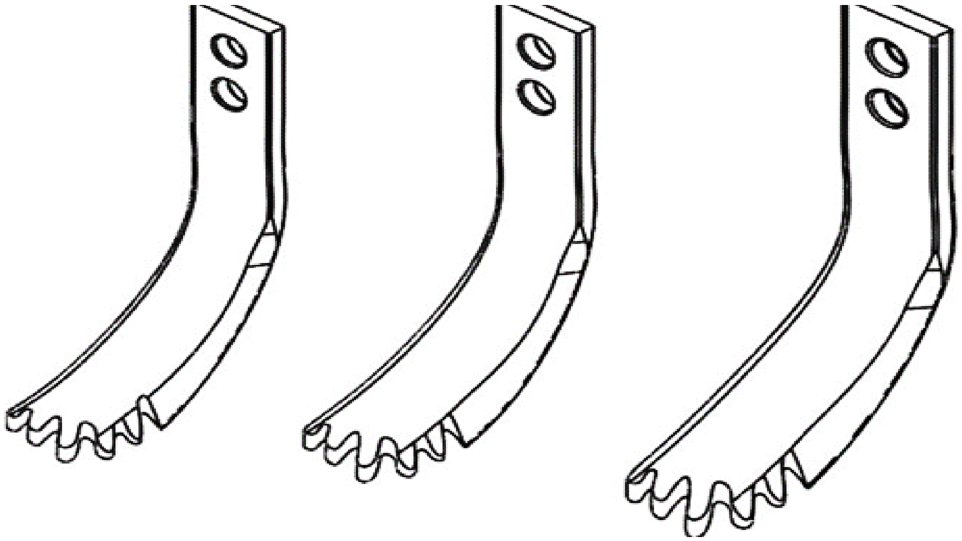


Fig. 9. Blades designed based on the principles of biomimetic design

3.3. Blade modeling process in finite element software

The model designed in SolidWorks software was saved in .x-t format and then imported into the Abaqus environment, which is presented in the continuation of different stages of the blade modeling and analysis process. In the Property module, all the required engineering properties for the blade were defined. Because the blade under analysis is made of one material, the material under study is homogeneous. In Table 2, the engineering specifications of the material used for the blade were selected based on the reference [30].

Table 2. Specifications of the engineering material used for the blade [30]

Engineering Properties	Unit	Amount
Density	(Kg.m-3)	7850
Elastic Modulus	(GPa)	200
Poisson's Ratio	--	0.3
Ultimate Stress	(MPa)	250

3.4. Definition of blade constraints and loading

At this stage, first the support and then the amount of load on the blade were defined. According to Fig. 10, the location of the blade holes is considered as a support, which was restricted in all different directions of movement and rotation of the blade. Fig. 10 also shows the location of the load on the blade. In Fig. 10, the image on the right, where the surface of the blade is highlighted in green, shows this area where the load is applied in a compressed manner, in which 400 Nm of load has been applied to all the models examined.

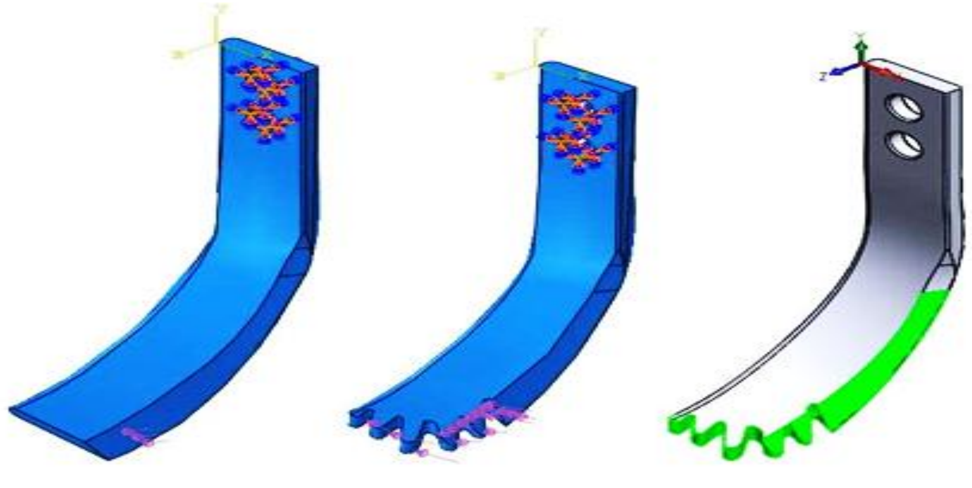


Fig. 10. The place of definition of the support and the place of applying load on the blade

3.5. Blade mesh

Meshing is often used in software-based simulation for finite element analysis and computational fluid dynamics and can significantly affect the accuracy of the simulation and the resources required to perform the simulation. Free meshing with quadrilateral elements can be applied to almost any three-dimensional region. Very complex models can be meshed using this technique without the aid of partitioning. In this research, meshing with tetrahedral elements was used, which is shown in Fig. 11, a schematic of meshed blades.

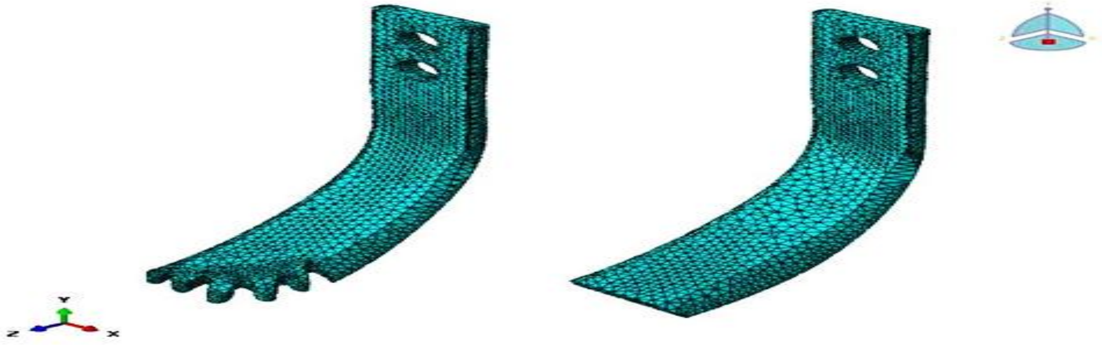


Fig. 11. Retracting the retainer blades

4. Results Analysis

Fig. 12 shows the stress distribution in the blade with a simple design and where the maximum stress occurred for the blade angles of 20°, 25°, and 30 °. As shown in Fig. 12, the maximum von Mises stress was observed in the area of the blade hole and its connection to the rotator flange, which was equal to 230.7 MPa. When the blade angle was increased to 25 degrees, the maximum von Mises stress decreased to 186.4 MPa. The stress distribution for this blade is similar to the previous case; in this case, the maximum stress was observed in the hole area of the blade. Then, with an increase in the blade angle, the maximum stress value decreased significantly compared to the 20° angle. However, compared to the 25° angle, the change in maximum stress had no significant effect, with the maximum stress value reaching 195 MPa.

Table 3 shows the maximum stress and reliability of the blade designed for different blade angles. By increasing the blade angle from 20 degrees to 25 and 30 degrees, the designed blade reliability increased from 1.08 to 1.34 and 1.28. However, when changing the blade angle from 25 to 30 degrees, the observed changes in maximum von Mises stress, and the reliability coefficient was less than 5%, which had no significant effect.

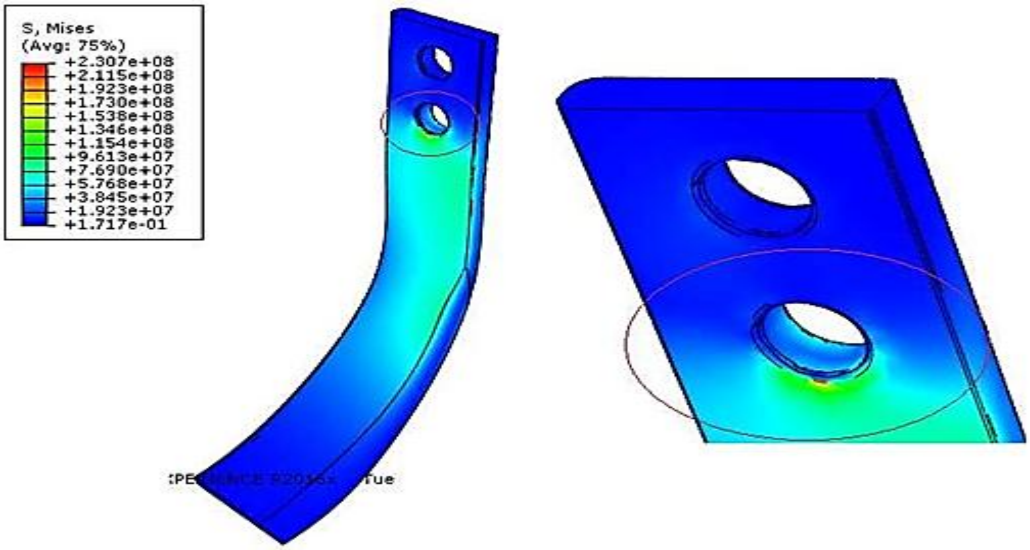


Fig. 12. Stress distribution in the blade with a simple design and blade angle of 20 degrees and the location of maximum stress

Table 3. Comparison of maximum stress and reliability for the blade designed for different blade angles

Model	Von-mises Stress (MPa)	F.S.
$Simple\ 20^\circ - 35^\circ$	230.7	1.08
$Simple\ 25^\circ - 35^\circ$	186.4	1.34
$Simple\ 30^\circ - 35^\circ$	195	1.28

4.1. Blade designed based on biomimetic

Fig. 13 shows the stress distribution in the blade, as well as the location of the maximum von Mises, stress for different designed blades. The results showed that the maximum von Mises stress per blade with angles of 20 °, 25 ° and 30 ° was equal to 10.3 MPa, 132.9 MPa and 124.3 MPa, respectively. In this scenario, by increasing the blade angle, the maximum stress level initially increased and then decreased again. In the stress analysis mode for the blade with a biomimetic design, the best blade had an angle of 20 degrees, with a blade reliability coefficient of 2.37 being observed. An examination of the position where the maximum stress occurred in the blade showed that the site of maximum von Mises stress was in the hole where the blade connects to the rotator flange.

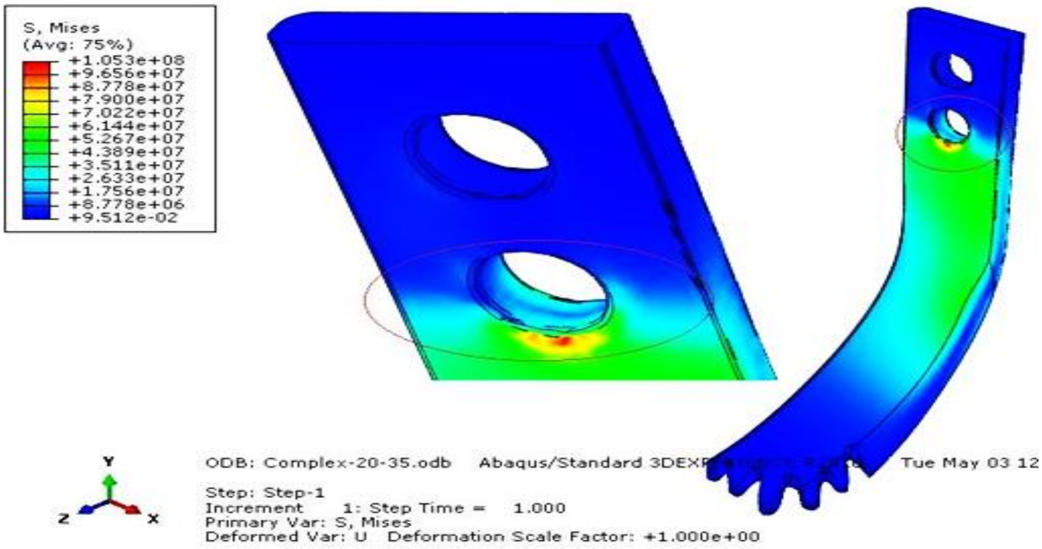


Fig. 13. Stress distribution in the blade with bio-simulator design and blade angle of 20 degrees and the location of maximum stress

Table 4 shows the maximum von Mises stress and the reliability coefficient for different blades designed by the biomimetic method. The results showed that in all the studied models, the maximum von Mises stress observed in the blade was always lower for the blade designed by the biomimetic method and its reliability was higher.

Table 4. Comparison of maximum stress and reliability for the blade designed for different blade angles

Model	Von-mises Stress (MPa)	F.S.
$Simple\ 20^\circ - 35^\circ$	105.3	2.37
$Simple\ 25^\circ - 35^\circ$	132.9	1.88
$Simple\ 30^\circ - 35^\circ$	124.3	2.01

4.2. Results of blade displacement analysis

Fig. 14 shows the study of displacement in the blades designed by the simple method for all three different blade angles. The highest displacement under a 400 N load was observed in a simple blade with an angle of 20 degrees, with a value of 1.29 mm. With the angle increasing to 25 and 30 degrees, the maximum displacement decreased by 12.40% and 10.85%, respectively.

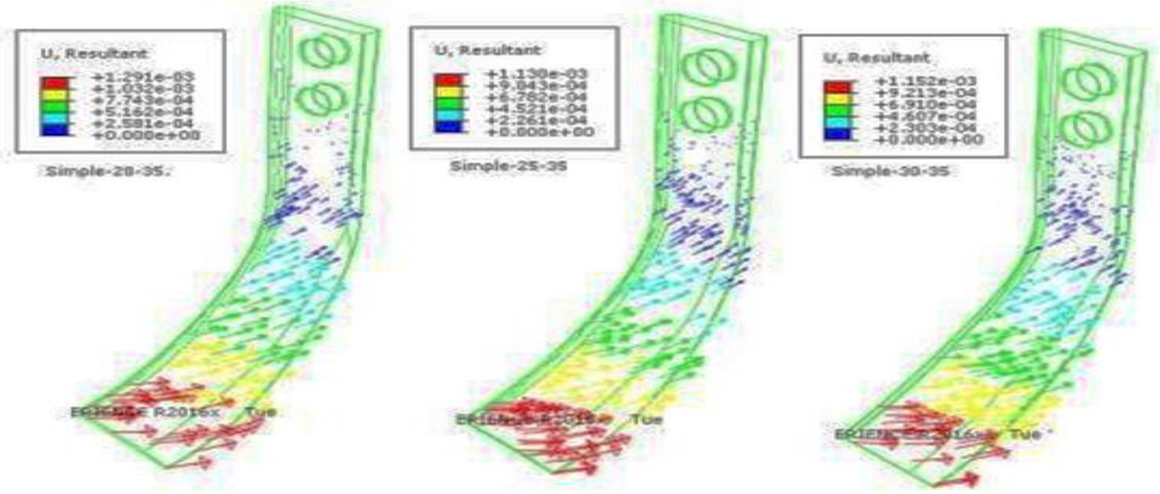


Fig. 14. Investigation of displacement in blades designed by simple method (from left to right blade angle 20, 25 and 30 degrees)

The study of displacement in the blades designed by the biomimetic method is shown in Fig. 15. However, the comparison between the maximum displacement in the blade with the simple design mode and the bio-simulator design showed that the maximum displacement in the blade in the bio-simulator mode was sharply reduced and in all blade angles, the amount of displacement in the bio-simulator blade was minimal.

Table 5 compares the maximum displacement values in the blades for the two design methods. The maximum displacement was observed in the blade with an angle of 20 degrees at 0.82 mm, which decreased to 0.79 mm and 0.76 mm with increasing the blade angle from 20 to 25 and 30 degrees, respectively.

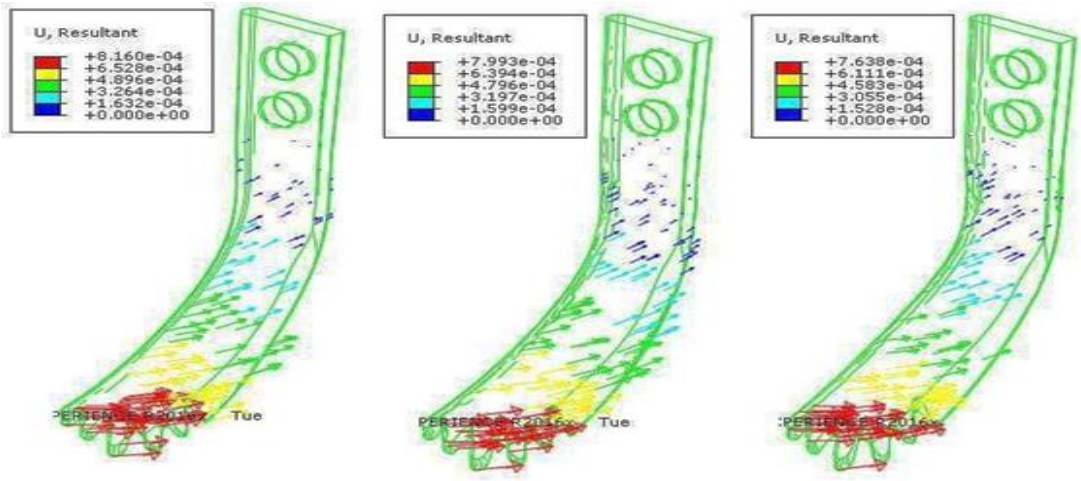


Fig. 15. Investigation of displacement in blades designed by a simple method (from left to right blade angles 20, 25, and 30 degrees)

Table 5. Comparison of displacement in different blades

Model	Total Deformation (mm)
$Simple\ 20^\circ - 35^\circ$	1.29
$Simple\ 25^\circ - 35^\circ$	1.13
$Simple\ 30^\circ - 35^\circ$	1.15
$Biomimetic\ 20^\circ - 35^0$	0.82
$Biomimetic\ 25^\circ - 35^0$	0.79
$Biomimetic\ 30^\circ - 35^0$	0.76

4.3. Results of absorbed energy analysis of the blade

Figs. 16 and 17 show the energy absorbed in the blades designed by the simple method and the biomimetic method for blade angles of 20, 25 and 30 degrees. In the simple design of the blade, with the increase of the blade angle, the amount of energy absorbed decreased, indicating that by increasing the blade angle, part of the energy due to the load of 400 Newtons passed through the blade, reducing its effect. However, in the case of biomimetic design, changing the blade angle showed no significant effect on the amount of energy absorbed in the blade.

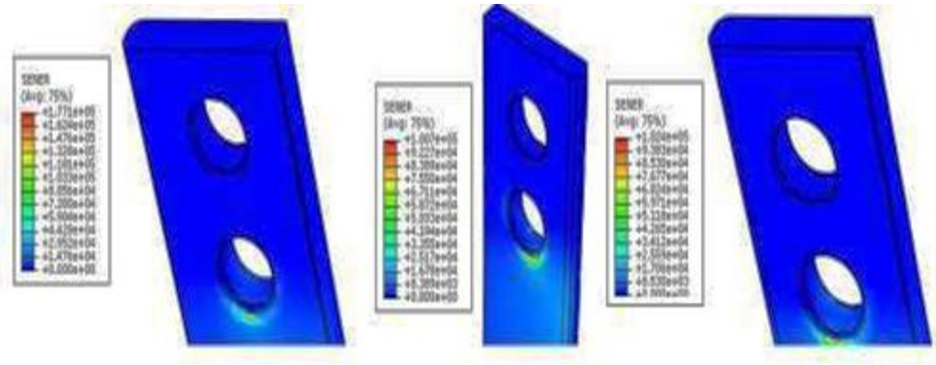


Fig. 16. Investigation of absorbed energy in blades designed by simple method (from left to right blade angle 20, 25 and 30 degrees)

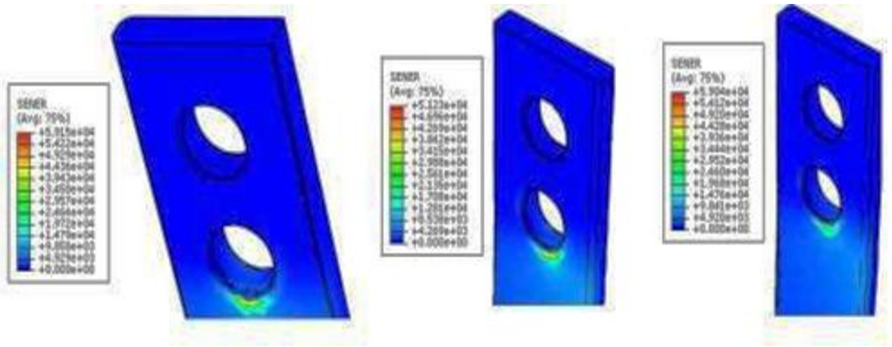


Fig. 17. Investigation of absorbed energy in blades designed by bio-simulator method (from left to right blade angle of 20, 25 and 30 degrees)

In Table 6, the absorbed energy levels for the blades designed using simple and biomimicry methods are compared, showing that in the bio mimic design method, the amount of energy available in the blade is greatly minimized, indicating an improvement in the designed blade.

Table 6. Comparison of displacement in different blades

Model	Energy
$Simple\ 20° - 35°$	1.77e5
$Simple\ 25° - 35°$	1.01e5
$Simple\ 30° - 35°$	1.02e5
$Biomimetic\ 20° - 35°$	0.59e5
$Biomimetic\ 25° - 35°$	0.51e5
$Biomimetic\ 30° - 35°$	0.59e5

4.4. General comparison of results

In Table 7, all the design parameters of the blades are compared in two modes: simple design and biomimetic design. As can be seen in the results, all parameters, including von Mises stress, displacement, energy absorbed and finally, the reliability coefficient in the biomimetic design mode compared to the blade with a simple design, have been improved. Table 7 also shows the effective blade level, which was calculated using Abacus software. By changing the type of design from simple to bio simulator, the effective surface of the blade increased, which caused the maximum stress on the blade to decrease. On the other hand, the blade torsion angle is one of the variables affecting changes and stress distribution in the blade. Although the effective area increases with increasing angle, a combination of the effective blade area and blade angle determines the final level of tone applied to the part. Because the purpose of designing a bio-mimic blade is to insist on soil and have maximum failure resistance, the design criterion and selection of the appropriate blade is the minimum von Mises stress and maximum reliability, so according to the current models, the best model to have the minimum von Mises stress and the maximum reliability of the biomimetic blade with an angle of 20 degrees. Finally, we suggest another material made of corrosion-resistant stainless steel composed of iron and carbon.

Table 7. Comparison between the results of biomarker design

Model	Von-mises Stress (MPa)	Total Deformation (mm)	BlaSurface (mm^2)	Pressure on the blade (MPa)	Energy	F.S.
$Simple20^{\circ} - 35^{\circ}$	230.7	1.29	1395	0.288	1.77e5	1.08
$Simple25^{\circ} - 35^{\circ}$	186.4	1.13	1518	0.263	1.01e5	1.34
$Simple30^{\circ} - 35^{\circ}$	195	1.15	1491	0.268	1.02e5	1.28
$Biomimetic20^{\circ} - 35^{\circ}$	105.3	0.82	2020	0.198	0.59e5	2.37
$Biomimetic25^{\circ} - 35^{\circ}$	132.9	0.79	2153	0.186	0.51e5	1.88
$Biomimetic30^{\circ} - 35^{\circ}$	124.3	0.76	2173	0.184	0.59e5	2.01

5. Conclusion

In all designed models, the maximum von Mises stress was observed in the area of the blade hole and its connection to the rotator flange, which was equal to 230.7 MPa for a simple blade with an angle of 20 degrees, which increased the blade angle to 25 degrees The maximum stress of von Mises decreased to 186.4 MPa. Also, in a simple blade, with increasing the blade angle from 20 degrees to 25 and 30 degrees, the reliability of the designed blade increased from 1.08 to 1.34 and 1.28, but for the blade with a bio-emulator design, the best blade angle is the angle. It was 20 degrees, for which the blade reliability was 2.37. The minimum displacement in the blade was observed for the biomimetic model, which increased the amount of maximum displacement in the change by increasing the blade angle in both design modes. Examination of the energy absorbed in the blade showed that the amount of energy absorbed in the blade with a simple design was higher than the blade with a bio-simulator design. In the blade mode with a simple design with increasing blade angle, the amount of energy absorbed decreased but in the case of biomimetic design; by changing the blade angle, no significant effect was observed on the amount of energy absorbed in the blade. The best model for designing a rotary tillage tool was an L-shaped blade with a bio-imitation design with an angle of 20 degrees. In this case, the maximum stress was reduced by 54.35% compared to the simple case, which increased the reliability of the blade from 1.08 to 2.37. Suggestions According to the results obtained in this research, it is suggested that a simple L-shaped blade and a bio-imitation blade be made with an angle of 20 degrees and its effect on tillage operations be investigated. It is suggested to study the combined effect of other parameters such as the tip angles of five mice, in the design of the biomimetic blade. It is suggested that the blade structure be optimized to have the maximum reliability using binomial algorithms such as genetic algorithm and differential reflection algorithm. Direction and the tractor arm are 10 degrees, and it suggested that in a separate study, the location of the arm connection to the hydraulic jack be redesigned to reduce the concentration of stress in that area.

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