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Design and Experiments of Biomimetic Stubble Cutter

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Abstract

The fore claws of the nymph of *Cryptotympana atrata* have excellent ability to cut and dig soil. Inspired by this, we designed a biomimetic stubble cutter to reduce the cutting resistance. Reverse engineering and 3D print technology were applied to design the biomimetic stubble cutter. Two types of biomimetic corn stubble cutters with different tooth heights (5 mm and 2.5 mm) were designed. The cutting ability of biomimetic corn stubble cutters was compared to the conventional design by the quadratic regression orthogonal test. Tooth height, dip angle of cutting edge, and cutting velocity were chosen as orthogonal test factors. The biomimetic stubble cutters show lower cutting resistance than the conventional one. Cutting velocity exerts the least effect on cutting resistance, followed by tooth height and dip angle of cutting edge. Optimal combination with the least cutting resistance is tooth height of 2.5 mm and dip angle of cutting edge of 40˚ while the cutting resistance does not vary remarkably with cutting velocity. Test results indicate the serrated structure design as a principal factor for cutting resistance reduction. The biomimetic stubble cutter design, inspired by the soil-cutting mechanism of *Cryptotympana atrata* nymph, remarkably improves the performance of stubble cutter.

Keywords: biomimetics, fore claws, stubble cutter, serrated structure, reverse engineering

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1 Introduction

The soil tillage machine is utilized in agricultural applications for surface soil cultivation[1]. A type of soil tillage machine includes the corn stubble harvester that operates by digging and scattering soil to collect the corn stubbles, ultimately reducing labor requirements[2]. Corn stubbles may be collected for the use of electricity generation as biomass energy, which is eco-friendly for avoiding the combustion of corn stubbles. The stubble cutter is a critical component of the corn stubble harvester with performance and work efficiency influencing working resistance of the unit and proficiency of picking up and collecting.

Working quality of the soil-engaging components and cutting tools are linked to both the parameters of soil (water content, soil compaction, *etc*.) and characteristics of the corn stubble while an efficient geometric structure design may reduce adhesion and resistance to improve work efficiency. Tagar *et al*.[3] analyzed the soil failure mode and revealed cutting resistances under different levels of consistency limits, tool rake angles and tillage depths based on cutting tests. Maciejewski *et al*.[4] analyzed the acting mechanism between earth-working machines and soil and optimized the acting parameters. However, the geometric structure of the earth-working machines was not optimized.

Ma *et al*.[5] designed an offset corn stubble cutter. The offset structure and slide-cutting effect of this stubble cutter design reduced working resistance and leakage rate of stubble. Quan *et al*.[6] optimized the stubble cutter's cutting edge curve and designed a cutter with a multilevel sliding cutting angle. The cutting test indicated that energy consumption was lower than that of the conventional cutter. Research then indicated that the geometric structure optimization of the cutting tools could reduce cutting resistance.

Research on the optimization of traditional agricultural machinery utilizing new developments in the bionics field has recently expanded. Bionics is an inter-

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disciplinary field, which connects biology with various engineering technical subjects through dynamic research options, principles and innovation methods[7,8]. The biomimetic design concept of agricultural mechanical components has been applied to reduce resistance and power consumption in many farming implements[9–11]. Tong *et al*.[12] researched the soil-engaging components and cutting tools, imitating the body surface structure of the dung beetle (*Copris ochus Motschulsky*) to design a biomimetic furrow opener. It was found that the working resistance was lower than that of the traditional cutter under different working velocities and depths. Jia *et al*.[13] designed a biomimetic saw blade inspired by serrated incisors of the grasshopper [*Chondracris rosea rosea* (De Geer)]. Average cutting force of the bionic saw blade was 51.56 N, which was 28.17% less than that of traditional saw blade. Li *et al*.[14] imitated the fore claws of mole rat (*Scaptochirus moschatus*) to design a biomimetic stubble-cutting disc. Finite Element Analysis (FEA) results showed the biomimetic stubble-cutting disc featured superior structural strength and cutting efficiency than the traditional design. Li *et al*.[15] also designed a biomimetic stubble cutter imitating thorns on the femur and tibia of praying mantis (*Mantis religiosa Linnaeus*) and the working resistance of stubble cutter was reduced. Past research provides a significant foundation for future biomimetic stubble cutter design improvements; however, a more suitable biological prototype exists.

Nymphs of *Cryptotympana atrata* live for 3–5 years 400 mm underground emerging from the soil to breed[16,17]. The nymph features a distinct ability to cut complex plant roots mixed with soil as a result of fore claws characteristics. The cutting process of stubble cutter resembles the behavior of nymph of *Cryptotympana atrata*, indicating a superior biological model in comparison with past research models. The nymph of *Cryptotympana atrata* then provides an improved biomimetic prototype for innovative stubble cutter design.

Geometric characteristics extraction from biomimetic prototypes is dependent on reverse engineering technology in bionic engineering field. Reverse engineering technology is widely applied in various fields and operates by retrieving surface data information through scanning an object[18–21]. The bionic engineering method utilizing creaturely functions, structures, behavior characteristics, and fundamental life processes is utilized in engineering theories and designs to build engineering structures similar to the creature. Reverse engineering technology is employed to obtain the geometric model of the applicable creature component to investigate the functional mechanism and to create the final technique or equipment based on bionic engineering[22–25].

The conventional stubble cutter is optimized in the study by imitating the fore claw of the *Cryptotympana atrata* nymph. Biomimetic specimens were manufactured by reverse engineering and 3D print technology. The performance of biomimetic stubble cutter then was compared with that of conventional one in terms of cutting resistance.

2 Materials and methods

2.1 Geometric characteristic of the fore claw

Five specimens of *Cryptotympana atrata* nymphs were collected from Shandong Province, China. A stereo microscope (SteREO Discovery. V20, Carl Zeiss Co., Ltd.) was used to observe the geometric structures. The fore claw of the nymph consists of femur, tibia and terminal claw (Fig. 1) with the serrated structure at the forepart of the femur used to cut soil and the sharp tibia and terminal claw used to dig soil[26].

2.1.1 Curve extraction of the serrated structure

The serrated structure at the femur's forepart is between femur and tibia (Fig. 2) with serrations varying in size and shape. Slide cutting action is performed on the side with a small dip angle reducing friction force and insuring emergence from the soil.

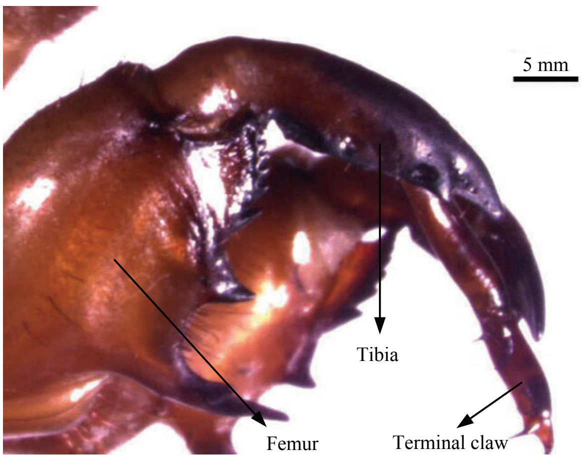

Fig. 1 The fore claw of the *Cryptotympana atrata nymph.*