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Design and performance evaluation of portable twin wheel weeder

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Abstract

Weed infestation is a significant challenge in agriculture, leading to substantial yield losses and increased production costs. This study focuses on the design, fabrication, and performance evaluation of a Portable Twin Wheel Weeder as an efficient, sustainable alternative to traditional and chemical weed management methods. Fabricated using lightweight materials, the weeder features a dual-wheel configuration for enhanced stability and operator comfort. Field experiments were conducted to compare its performance with the Existing Twin Wheel Weeder and Improved Twin Wheel Weeder**,** evaluating parameters such as weeding efficiency, field efficiency, soil mass manipulation, plant injury, and ergonomic factors. The results demonstrated that the Portable Twin Wheel Weeder achieved the highest weeding efficiency (90.90%) and field efficiency (92.98%), outperforming the Improved (88.33% and 88.33%) and Existing Weeders (86.76% and 85.29%). It also recorded the highest soil mass manipulation (4480 cm^3 per 200 cm run) and the lowest plant injury rate (5.45%), ensuring effective weed removal with minimal crop damage. The ergonomic evaluation indicated reduced operator fatigue, highlighting its user-friendly design. Additionally, the weeder's cost-effective and environmentally friendly design reduces dependency on chemical herbicides, promoting sustainable agricultural practices. The Portable Twin Wheel Weeder proved to be a versatile and efficient tool for weed management, offering significant benefits in terms of productivity, cost savings, and environmental sustainability. Its adaptability to small-scale farming systems makes it a promising solution for resource-constrained farmers, contributing to improved agricultural outcomes and operator satisfaction.

Keywords: Agricultural weeder, mechanical weeder, machine design, sustainable agriculture, weed control

Introduction

Weeds are a major obstacle to agricultural productivity worldwide, including in India, where agriculture forms the backbone of the economy and provides livelihood to nearly half of the population. Weed infestation poses a significant challenge, costing the Indian agricultural sector approximately USD 11 billion annually (Chauhan, 2020) [2]. Additionally, millions of tonnes of food grains are lost annually due to unchecked weed growth, underscoring the critical need for efficient and sustainable weed management solutions, particularly for smallholder farmers reliant on manual labor.

Weeds, defined as unwanted plants competing with crops for resources such as sunlight, water, and nutrients, pose multiple threats to agriculture. They reduce crop yields, harbor pests and pathogens, contaminate harvests, and complicate post-harvest processes (Monaco, 2002) [7]. Depending on their life cycle, weeds can be classified into annuals, biennials, and perennials, each requiring specific control strategies (Sutherland, 2004) [10]. Without effective weed management, weeds can deprive crops of up to 40% of soil nutrients, significantly reducing yields (Abbas *et al*., 2018; Rana and Rana, 2016) [1, 8]. Furthermore, some weeds act as hosts for pathogens or parasitic plants, exacerbating agricultural losses.

Traditional weed control methods in India, such as hand tools like hoes and cutlasses, remain prevalent among smallholder farmers. However, these methods are labor-intensive, time-consuming, and impractical for large-scale operations (de Araújo *et al*., 2020; Guru *et al*., 2018) [3, 6]. Chemical herbicides, although effective, pose environmental and health risks, including soil degradation and toxicity. As a result, the demand for alternative, sustainable weed control technologies has grown, with mechanical weeders emerging as a promising solution.

The development of agricultural weeders has progressed significantly in recent years, focusing on improving efficiency and reducing manual labor. Raut *et al*. (2013) [9] emphasized that mechanization enhances productivity, conserves inputs, and reduces costs, enabling sustainable farming practices for small-scale farmers. Devanathan *et al*. (2021) [4] developed a cost-effective weeder with dual blades, costing 4000 rupees, offering an affordable solution for weed removal. Guru *et al*. (2018) [6] introduced a power-operated single-row dry land weeder that demonstrated superior weeding efficiency and reduced operational costs, proving its suitability for inter-row weeding in rice crops. Diwan *et al*. (2022) [5] designed a transmission system with a two-stage speed reduction using V-belt and chain drives, ensuring optimal power delivery and improved machine performance. These studies collectively highlight critical parameters for successful weeder designs, including field efficiency, ease of use, and adaptability.

In India, rising labor costs and inefficient manual methods highlight the pressing need for improved weeding technologies. Among mechanical weeders, the twin-wheel weeder stands out for its simplicity, portability, and ease of use. These manually operated devices, featuring dual wheels for stability and maneuverability, are suitable for various field conditions and smallholder farmers with diverse cropping systems.

This research focuses on the development and evaluation of a Portable Twin-Wheel Weeder, designed to overcome the limitations of traditional tools. The primary objective is to create a lightweight, easy-to-operate device capable of efficiently removing weeds without disturbing the soil. The dual-wheel configuration ensures stability and reduces operator fatigue during prolonged use. The weeder's portability allows it to adapt to different terrains, making it a versatile tool for weed control. Field tests will assess its weed removal efficiency, usability, and impact on soil health, comparing it with traditional and existing devices. Additionally, the study aims to explore its potential for reducing labor costs, minimizing chemical herbicide use, and promoting sustainable farming practices.

Material and Methods

This study aimed to design, fabricate, and evaluate the performance of a Portable Twin Wheel Weeder (PTWW) in comparison with an Existing Twin Wheel Weeder and a Modified Twin Wheel Weeder. The methods employed include fabrication, design analysis, field testing, and ergonomic evaluation, as detailed below.

Fabrication of Portable Twin Wheel Weeder

The fabrication of the Portable Twin Wheel Weeder was carried out at the Farm Machinery and Power Department workshop, CAET, AAU, Godhra. The fabrication process involved cutting, welding, grinding, folding, drilling, and riveting mild steel strips to create the various components of the weeder. Lightweight plastic fiber wheels were used to reduce both the weight and cost of the machine. Once fabricated, the components were assembled and painted to complete the weeder.

Design analysis

The design of the Portable Twin Wheel Weeder focused on improving structural integrity and performance. The shaft design was calculated based on its ability to withstand bending moments and torsional stresses. By using mild steel in place of the traditional shaft, the new design improved the weeder's durability while reducing the overall complexity. The force and bending moment calculations were based on the weight distribution between the wheels, ensuring balance during operation.

Design specifications

The Portable Twin Wheel Weeder was designed with specific dimensions and materials to optimize performance (Table 1). The weeder is a manual tool with an overall dimension of 153 × 28 cm and a weight of 4.0 kg. It has a working width of 28 cm, and the handle height is adjustable to 145 cm from the ground level. The wheels have a diameter of 25 cm and a width of 30 cm, ensuring stability and ease of movement in the field.

Table 1: Specification of Portable Twin Wheel Weeder

Details	Particulars
Type of hand hoe	Manual
Overall dimension (L X B), cm	153 X 28
Weight, Kg	4.0
Working width, cm	28
Adjustable handle height, cm	145
Blade dimensions, cm	10.5 X 28 X 0.3
Ground wheel diameter X width, cm	25 X 30

Development of portable twin wheel weeder

The Portable Twin Wheel Weeder was developed with a focus on uprooting weeds efficiently by applying shearing force to the weed stems and disturbing the soil. The weeder was designed using mechanical principles to determine the force, bending moments, and shaft size. After assembly, the machine was tested for its field performance, as shown in Figure 1.

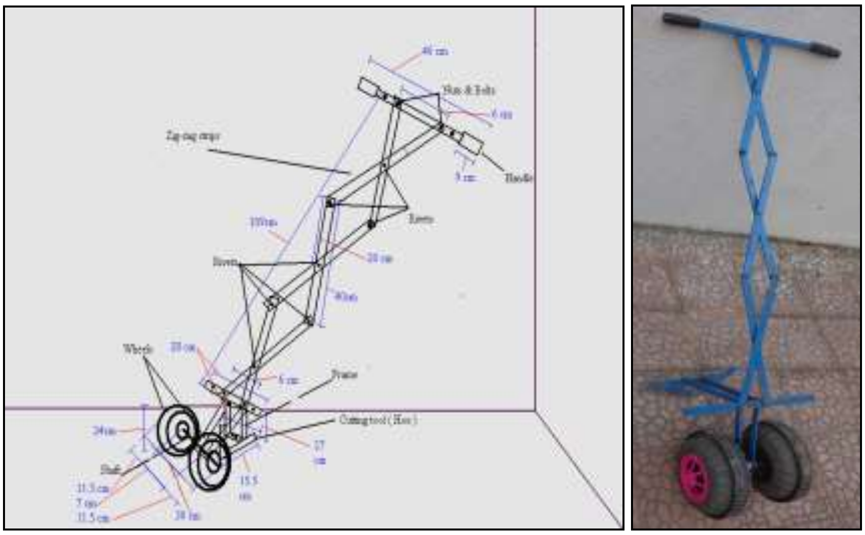

Fig 1: Portable twin wheel weeder

Description of study area

Field experiments were conducted at the Instructional Research Farm, Kakanpur, CAET, AAU, Godhra. The site is located in a semi-arid region with sub-humid weather conditions. The latitude, longitude, and elevation of the study area were recorded using GPS. The area experiences an annual rainfall of 1047 mm, with winter temperatures ranging from 15 °C to 30 °C and summer temperatures between 30 °C and 42 °C. These weather conditions were considered during the testing of the weeder in the maize-growing season.

Testing of Portable Twin Wheel Weeder

The field performance of the Portable Twin Wheel Weeder was compared with that of the Existing Twin Wheel Weeder and the Modified Twin Wheel Weeder. The parameters studied during the testing included:

Soil moisture content

Measured using a digital TDS soil moisture meter. The average moisture content was calculated before field operations.

Soil mass manipulation

The disturbed soil was measured to assess the efficiency of the weeder in soil manipulation. The soil mass was calculated using the formula

$$SMM = W \times d \times 100$$

SMM = Soil mass manipulated, cm^3
W = Width of operation, cm
d = Depth of operation, cm

Field efficiency

Both theoretical and effective field capacities were calculated using the formulas for theoretical field capacity (TFC) and effective field capacity (EFC). The field efficiency was determined by comparing these values.

$$TFC = \frac{S \times w}{10}$$

TFC = Theoretical field capacity, ha/hr
S = Average speed of implement, km / hr
w= Rated width of implement, m

$$EFC = \frac{w \times l}{t \times 10}$$

Where,
EFC = Effective field capacity, ha/hr
S = Actual speed of implement, km / hr
w = Rated width of implement, m

Weeding efficiency

The percentage of weeds removed by each weeder was calculated by counting the number of weeds before and after weeding operations.

$$WE = \frac{W_1 - W_2}{W_1} \times 100$$

Where,
WE = Weeding efficiency
W_1 = Numbers of weeds present before weeding
W_2 = Numbers of weeds present after weeding

Plant injury

The percentage of plant injury was determined by comparing the number of plants before and after weeding.

$$\text{Percentage of plant injury (\%)} = \frac{q}{p} \times 100$$

Where,
q = no. of plant in 10 m row length after weeding,
P = no. of plant in 10m row length before weeding,

Ergonomic factors

The ergonomic performance of the Portable Twin Wheel Weeder was evaluated based on operator comfort during field operations. Although detailed data on heart rate, pulse rate, and oxygen consumption could not be collected due to a lack of instruments, operators reported less fatigue and tiredness when using the Portable Weeder compared to the Existing and Modified versions. This suggests that the new design offers better ease of use and operator efficiency.

Result and Discussion

Design analysis

The design and analysis of the shaft for the Portable Twin Wheel Weeder were conducted to ensure its structural stability and efficiency during field operations. The shaft was subjected to load distribution and bending moment calculations, as detailed below.

Load distribution

The total weight of the weeder (W) was measured to be 6 kg. To determine the weight distribution between the two supports (RA and RB), the equilibrium equation W=RA+RB was applied. By taking moments about point A, the reaction force at RB was calculated as follows:

M_A=0=W×RA−Y×RB (RA=RB= 3 Kg)

The results indicate that the load is equally distributed, with 3 kg at each support.

Bending Moment

The bending moment at a specific point X equidistant from supports A and B, was analyzed to evaluate the maximum stress experienced by the shaft. The distances from A to X (D_1) and X to B (D_2) were both assumed to be 15 cm.

The bending moment at X 90 kg-cm

The results of the shaft design analysis confirm that the maximum bending moment experienced by the shaft is 90 kg-cm. This value demonstrates the structural integrity of the shaft, ensuring that it can withstand the applied loads during weeder operation without failure or deformation. The equal weight distribution of 3 kg on each support further ensures balanced operation, reducing the risk of instability during field use.

Soil moisture content
The soil moisture content was recorded to assess its impact on weeder performance. The moisture content of the soil ranged from 59.00% to 68.42%, with an average value of 65.09% This data is crucial as moisture content affects the ease of weeding and the machine's efficiency in soil penetration and weed removal.

Soil mass manipulation
The average soil mass manipulation was calculated for the Portable Twin Wheel Weeder, Existing Twin Wheel Weeder, and Improved Twin Wheel Weeder (Figure 2). The Portable Twin Wheel Weeder demonstrated the highest soil mass manipulation at 4480 cm³ per 200 cm run, followed by the Improved Weeder (3045 cm³) and the Existing Weeder (2808 cm³). Although all three weeders performed similarly in terms of soil depth penetration, the Portable Weeder showed superior efficiency in handling larger volumes of soil, which suggests improved weed removal capabilities and soil aeration (Figure 3).

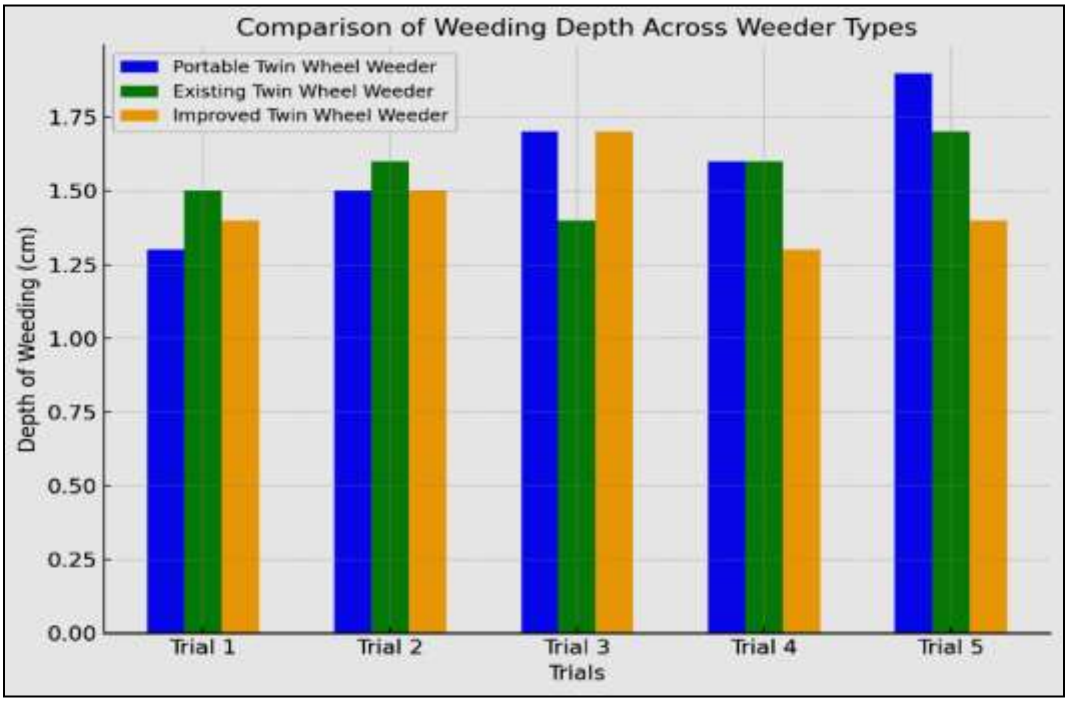

Fig 2: Comparison of weeding depth across weeder types

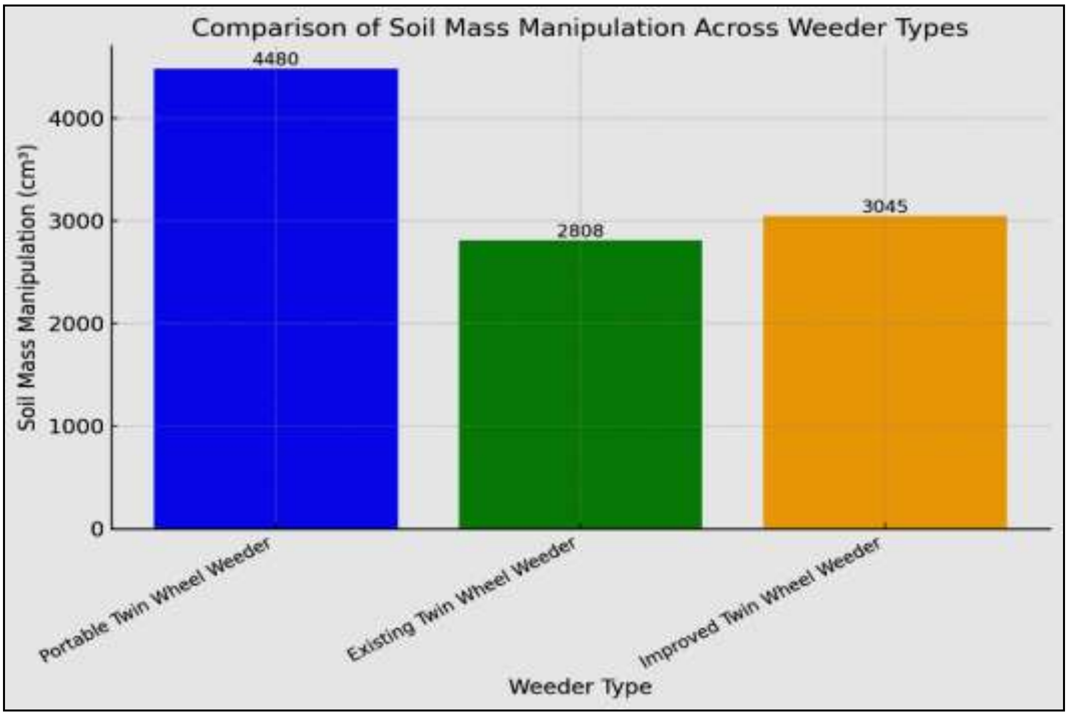

Fig 3: Comparison of soil mass manipulation across weeder types

Field Efficiency

The Portable Twin Wheel Weeder achieved the highest field efficiency (92.98%) compared to the Existing Weeder (85.29%) and the Improved Weeder (88.33%), as shown in Figure 4. The effective field capacity of the Portable Weeder was 0.0534 ha/hr, which is higher than both the Existing and Improved Weeders. This suggests that the Portable Weeder is more efficient in terms of time and labor, covering more ground with less effort.

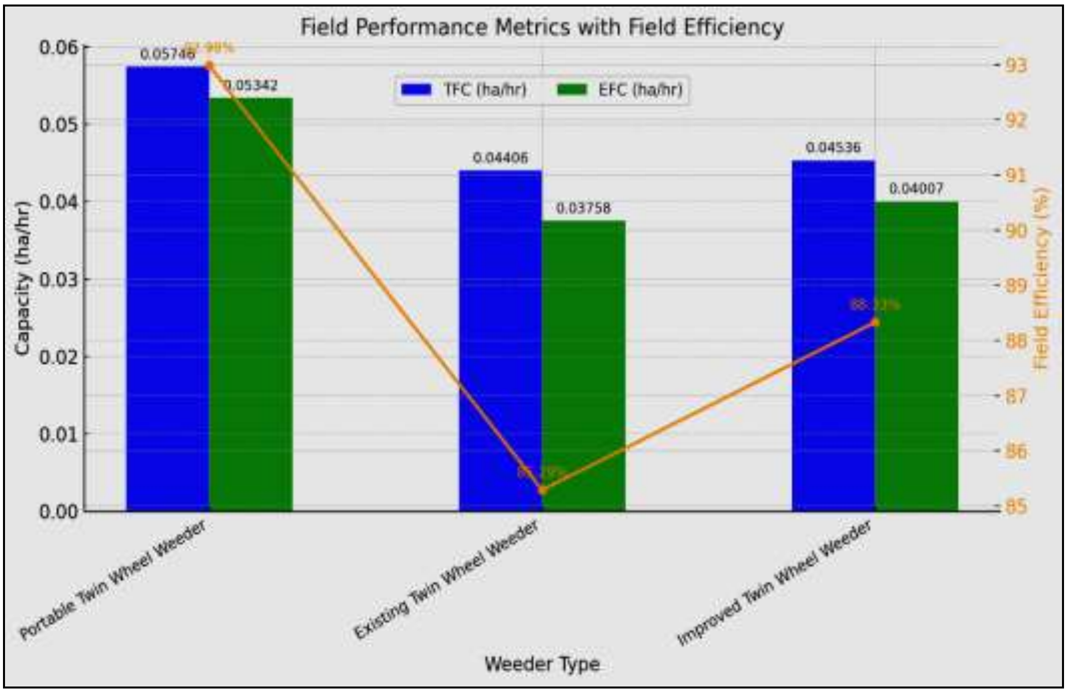

Fig 4: Field performance metrics with field efficiency

Weeding Efficiency

The weeding efficiency of the three weeders was compared by calculating the percentage of weeds removed during operation (Figure 5). The Portable Twin Wheel Weeder demonstrated the highest weeding efficiency (90.90%), followed by the Existing Weeder (88.33%) and the Improved Weeder (86.76%). The superior performance of the Portable Weeder in weed removal highlights its effectiveness in minimizing manual labor while maintaining high weeding standards.

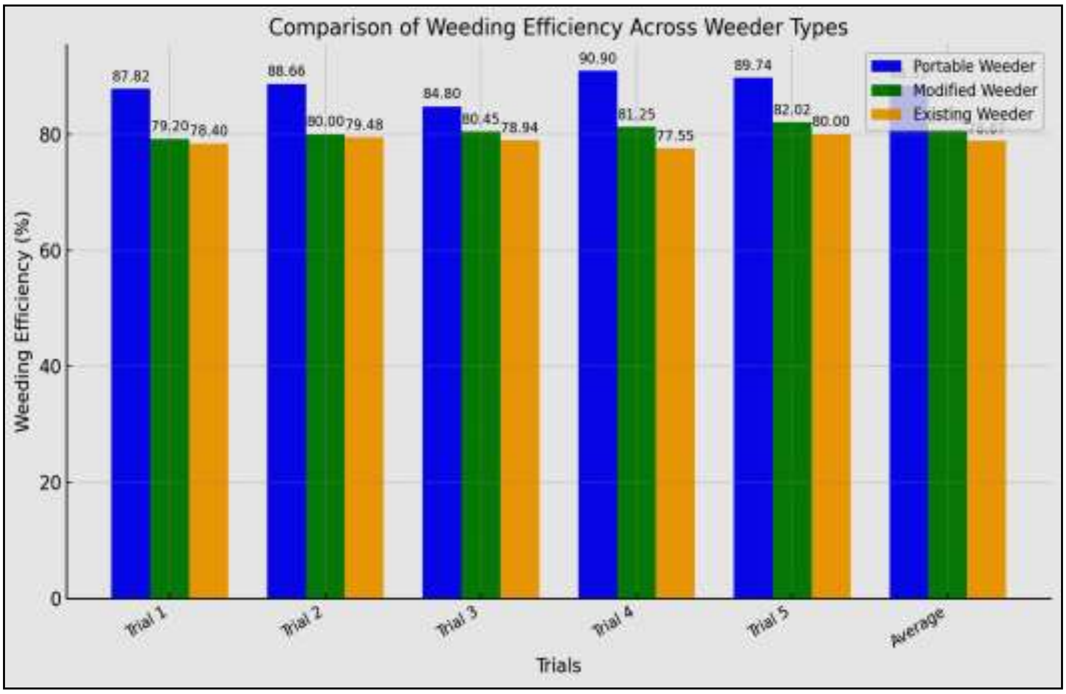

Fig 5: Comparison of field efficiency across weeder types

Plant injury
Plant injury, an essential factor in evaluating weeding tools, was minimal for the Portable Twin Wheel Weeder at 5.45%, compared to 9.09% for the Existing Weeder and 9.69% for the Improved Weeder (Figure 6). This lower plant injury rate suggests that the Portable Weeder is gentler on crops while still effectively removing weeds, making it a preferable option for delicate row crops.

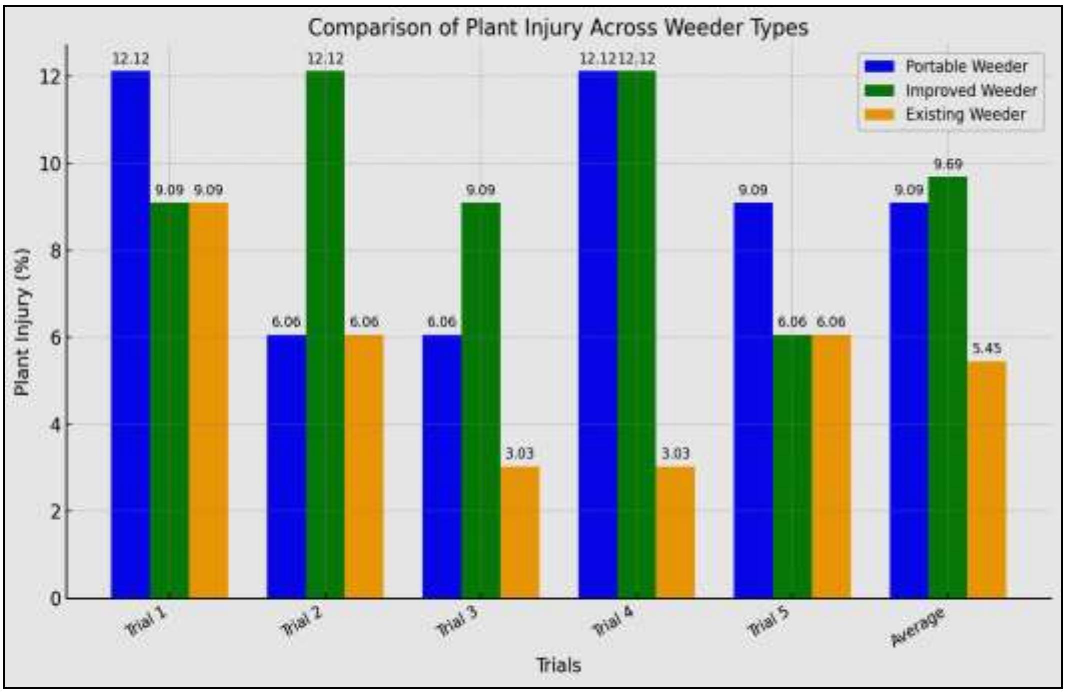

Fig 6: Comparison of plant injury across weeder types

Ergonomic factors
The Portable Twin Wheel Weeder also demonstrated advantages in terms of operator comfort and ergonomics. Although specific ergonomic data could not be recorded due to the lack of instruments, user feedback indicated reduced tiredness and fatigue when using the Portable Weeder compared to the Existing and Improved models. This suggests that the Portable Weeder is better designed for ease of use, which can enhance productivity and operator satisfaction in the field.

Conclusions
The Portable Twin Wheel Weeder achieved the highest weeding efficiency of 90.90% and field efficiency of 92.98%, outperforming the Improved Twin Wheel Weeder (88.33% weeding efficiency) and the Existing Twin Wheel Weeder (86.76% weeding efficiency). Its superior weed removal capability was evident across all trials. Operators experienced reduced fatigue and increased comfort while using the Portable Twin Wheel Weeder**,** due to its lightweight design and dual-wheel stability. This makes it highly suitable for prolonged use in diverse agricultural conditions. The Portable Twin Wheel Weeder demonstrated the highest soil mass manipulation of 4480 cm^3 per 200 cm run, surpassing the Improved Twin Wheel Weeder (3045 cm^3) and the Existing Twin Wheel Weeder (2808 cm^3). This indicates its ability to effectively aerate soil and uproot weeds. The Portable Twin Wheel Weeder recorded the lowest plant injury rate of 5.45%, compared to 9.09% for the Existing Twin Wheel Weeder and 9.69% for the Improved Twin Wheel Weeder**,** highlighting its gentleness on crops and suitability for row cropping systems.

The lightweight and durable construction of the Portable Twin Wheel Weeder reduced fabrication costs while ensuring high adaptability across various terrains, making it an economically viable option for smallholder farmers. By significantly reducing the need for chemical herbicides, the Portable Twin Wheel Weeder promotes eco-friendly farming practices, contributing to soil health and biodiversity preservation. The Portable Twin Wheel Weeder demonstrated its potential to improve agricultural productivity, minimize labor dependency, and enhance operator satisfaction, making it an effective and sustainable solution for small-scale farming systems.

Conflict of interest
No potential competing interest was reported by the author(s).

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