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Development and validation of a prototype of a manual intra-row mechanical weeder in vegetable beds

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Abstract

Aim of study: The present work addresses aspects related to the development of a prototype of a weeder capable of managing invasive plants in vegetable beds.

Area of study: The investigation was performed in the Federal Rural University of Rio de Janeiro, Seropédica (Brazil).

Material and methods: The methodology was divided into defined steps from planning and conceptual design, obtaining preliminary and detailed designs, to evaluating the performance of the physical prototype. The variant considered most appropriate was selected according to the project's feasibility index and was chosen for the development of the preliminary design and detailed design.

Main results: Based on the results obtained, it can be stated that the concepts used, and the prototype developed were functional and innovative for weed control in a lettuce crop, enabling the mechanical removal of weeds from 70.3% of the plants and increasing the working area by 49.3%. This indicates improved efficiency in the vegetable production process in raised beds.

Research highlights: The developed and validated mechanical weeder prototype allowed efficient weed removal and greater operational efficiency during lettuce cultivation in raised beds.

Keywords: agricultural machinery design; invasive plants; morphological matrix; vegetables.

Desarrollo y validación de un prototipo de una escardadora mecánica manual intra-fila en camas de hortalizas

Resumen

Objetivo del estudio: El presente trabajo aborda aspectos relacionados con el desarrollo de un prototipo de escardadora capaz de gestionar plantas invasoras en camas de hortalizas.

Área de estudio: La investigación se llevó a cabo en la Universidad Rural Federal de Río de Janeiro, Seropédica, Brasil.

Material y métodos: La metodología se dividió en pasos definidos desde la planificación y el diseño conceptual, obteniendo diseños preliminares y detallados, hasta evaluar el rendimiento del prototipo físico. Se seleccionó la variante considerada más apropiada según el índice de viabilidad del proyecto y se eligió para el desarrollo del diseño preliminar y detallado.

Principales resultados: Basándose en los resultados obtenidos, es posible afirmar que los conceptos utilizados y el prototipo desarrollado fueron funcionales e innovadores en el control de las malas hierbas en el cultivo de lechuga, permitiendo la eliminación mecánica del 70.3% de las plantas invasoras y un aumento del 49.3% en el área trabajada, lo que indica una mejora en la eficiencia en el proceso de producción de hortalizas.

Aspectos destacados de la investigación: El prototipo desarrollado fue funcional, ya que permitió controlar las malas hierbas eficientemente y llevó a un incremento del 49.3% de la efectividad operacional.

Palabras clave: diseño de maquinaria agrícola, hortalizas, matriz morfológica, plantas invasoras.

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Introduction

In recent years the state of Rio de Janeiro (Brazil) has been experiencing an increase in the production of crops such as tomato, lettuce, arugula, and spinach in its productive zones. Within a scenario of demand for healthier and higher quality products, vegetable production through organic systems has been gaining increasing prominence (Sediyama et al., 2014).

Thus, Kumar et al. (2022) mentioned that the competitiveness of producers in this production system depends on the diversity of cultivated products in the same area, lesser dependence on external resources, more efficient management techniques, and proper management of external resources used, such as the use of vegetative cover, considered preventive against the appearance of weeds (Santos et al., 2012; Mahmood et al., 2015).

Brown & Gallandt (2018) described that in organic production systems, weed control remains a complex practice based on the species identification present at the site, infestation density, climatic conditions, and regional characteristics. Consequently, conventional control is typically carried out between crop rows or around the target crop using devices that often feature limited technology, making them accessible for widespread use (Failla et al., 2021).

According to Jiao et al. (2022), current conventional production systems employ different weed removal methods, including manual and chemical methods, based on the use of herbicides. Conversely, in organic systems, the adoption of practices such as herbicide use is prohibited, with mechanical weed control being the most used method by producers, especially small-scale producers (Costa et al., 2018)

Woyessa (2022) asserted that mechanical weeding is potentially more sustainable than chemical weeding, due to lower costs and environmental suitability. Therefore, mechanization applied to small-scale vegetable producers becomes crucial, despite needing more efficient projects prioritizing ergonomic and safety aspects (Pallottino et al., 2018).

Currently, a significant portion of the agricultural machinery sector is increasingly seeking new technologies that can be adapted for use on small rural properties (Van Loon et al., 2020). It is also worth noting that to obtain suitable projects, several stages are executed, starting with conceptual and preliminary planning and design, moving on to detailed project development, production preparation, prototype construction, validation in field trials, and product launch (Severo et al., 2014; Grupioni et al., 2018).

In general, the development of agricultural machinery directly depends on identifying problems and subsequently applying methods that allow greater flexibility in managing project stages, enabling more innovative machines (Grzebieluckas et al., 2011; Almeida et al., 2012). Additionally, it is worth highlighting that errors in the design are mainly caused by the failure to apply engineering knowledge and design methodology, resulting in possible shortcomings in conceptualization and prototype development, necessitating validation to ensure that operational and safety requirements are met (Machado et al., 2023).

Among all the types of projects developed in recent years aiming to improve the mechanical control process, Chang et al. (2021) describe that current machines generally adopt different principles such as oscillation, rotation, and hybrids for the mechanical weed control process, highlighting primarily the challenge of obtaining a design that optimizes transmission mechanisms and reduces components for simple and efficient designs.

Different authors have considered that invasive plants can directly impact crop productivity, causing total losses of up to 30%, especially in organic production systems (Tejas et al., 2019). Therefore, potential solutions to the current challenges of mechanical weeding must be carefully considered, both now and in the future, for the development of commercial weeding machines (Machleb et al., 2020).

Based on all the points discussed, this study aims to present the design and development of a prototype capable of mechanically removing invasive plants from vegetable beds. Additionally, it aims to evaluate and validate the prototype in a real field setting on a farm.

Material and Methods

Conceptual project development

The team from the Agricultural Machinery Prototyping Laboratory at the Department of Engineering of the Federal Rural University of Rio de Janeiro (DE-UFRRJ/Seropédica, Brazil) conceptualized a prototype capable of mechanically removing invasive plants from vegetable beds, considering the reality of small vegetable producers in bed systems, with little use of technology and limited financial resources.

The machine design was developed using the methodology described by Pahl et al. (2005), where the entire prototype development process involved comparing tasks and combined with the morphological matrix method, obtaining viable solutions, resulting in a machine concept (Moreira et al., 2013).

Next, subfunctions of the prototype specific to the machine concept were defined to achieve the objective proposed by the team. According to the methodology described by Moreira et al. (2016), the subfunctions were divided and studied individually, which allowed for greater autonomy and ease in choosing the appropriate mechanisms for the machine.

Thus, it was possible to define a set of five subfunctions as follows: (1) Uproot the plant, (2) Transport the plant, (3) Support the machine, (4) Provide energy, and (5) Move the machine, where it was possible to make a rational choice of the best solution or mechanism that met each chosen subfunction, resulting in a grouping called a solution variant.

The morphological matrix of the machine's subfunctions (rows) and solution mechanisms (columns) was assembled according to the methodology described by Pahl et al. (2005), with the aim of determining various variants to solve a specific problem. Using the morphological matrix, it was possible to define the project variants in such a way that all sub-functions were performed in the most efficient manner.

The evaluation of the sub-functions was carried out according to technical and economic criteria. The prototype development team adopted a rating scale from 6 to 10, thus establishing that a poor score for one of the factors would not be sufficient to discard an option that included it. Therefore, based on the criteria adopted by the team, it was possible to obtain project viability indexes (PVI) ranging from 0.60 to 1.67.

Based on the above, the final scores of each mechanism for each determined subfunction were summed with the other subfunction mechanisms of the five previously established variants, allowing the variant that obtained the highest score to define the concept of the machine prototype developed in the project.

Virtual and physical prototype development

The present stage was conducted according to the definition of the prototype concept. According to Woyessa & Olaniyan (2023), especially in the development of agricultural machines aimed at mechanical weeding, it is necessary to consider agronomic parameters, such as crop variety, row spacing, weeding time, soil physical properties, and the power required to operate the machine under field conditions.

Thus, based on the scores given by the team and the definition and understanding of the machine concept to be developed, all structural parts were conceptualized using the CAD platform SolidWorks® 2010, which allowed for the creation of the conceptual design and virtual prototype of the machine.

It is also emphasized that all measurements used in this stage followed commercial standards to facilitate the future assembly of the prototype. Therefore, to obtain a definitive product drawing, all necessary and/or performed design changes had to be previously justified by the team as the stages progressed.

Next, the stage of constructing the physical prototype began, where it was possible to obtain an archetype based on the materials, mechanisms, and scales defined in the conceptual design. In the present project, no values for parts and services were established, as the acquisition of all materials and tools was supported by the institution to which the authors were affiliated.

Prototype usage performance

The tests to determine the performance of the developed prototype were conducted in the *Fazendinha Agroecológica* area, an area designated for organic agriculture, located at km 47 of the old Rio-São Paulo highway, in the municipality of Seropédica (RJ) (22º45'06" S and 43º40'25" W, at an altitude of 33 m). The climate belongs to the Aw class (tropical semi humid), according to Köppen, characterized by a mild and dry winter, with frequent rains and very high temperatures during the summer. The soil in the experimental area is classified as Dystrophic Red Argisols A (Ultisols), medium/sandy texture (Embrapa, 2006; Carvalho et al., 2013).

Initially, two beds cultivated with lettuce (*Lactuca sativa* L.) were chosen for the evaluation of the performance of mechanical weed control 42 days after the crop was established. Before weeding, the beds were irrigated, which is a commonly used practice that facilitates the action of the pulling mechanisms of the machines used.

Additionally, before the test, the species and number of invasive plants, and the degree of weed infestation were identified and quantified. Two predominant species were present, broadleaf woodsorrel (*Oxalis latifolia Kunth*) and purple nutsedge (*Cyperus rotundus* L.), with an average density of 83.16 plants m^{-2} in the evaluated plots, considered a low density (Silva et al., 2008). These invasive species are characterized by thin, spontaneous leaves and thrive in acidic and hard-to-manage soils (Pereira & Melo, 2008).

The experimental design was completely randomized, with six repetitions, and the treatments consisted of weeding with the developed prototype (T1) and manual weeding with a hoe (T2), totaling twelve experimental plots. Each plot to be weeded was an area of 1.0 m^2 of the bed (1.0 length x 1.0 width), thus making it possible to verify the performance and efficiency of the systems used.

Regarding the performance of the evaluated weeding systems, to determine the overall efficiency of invasive plant removal by the adopted systems, the removal of the aerial part with or without the root system was considered (Eq. 1). To determine the efficiency of removing plants with root systems, the total removal of the plant, including the aerial parts and root system, was considered (Eq. 2).

$$Efr = \left(\frac{Pr}{Pt}\right) x100 \qquad \text{(Eq. 1)}$$

$$Efs = \left(\frac{Ps}{Pr}\right) x100 \qquad \text{(Eq. 2)}$$

where, Efr: efficiency of weed removal, %; Pr: number of plants removed; Pt: total number of plants; Efs: efficiency of weed removal with root system, %; Ps: number of plants removed with root system.

Additionally, the determination of the operational capacity was based on the prototype's performance during operation, as this performance parameter expresses the amount of area worked in relation to the time required for the operation, according to the methodology described by Mialhe (1974), as shown in Eq. 3.

$$Cop = \frac{A}{Ts} \qquad \text{(Eq. 3)}$$

where Cop: operational capacity, m^2 min^{-1}; A: worked area, m^2; Ts: Time spent on the operations, min.

The data were subjected to analysis of variance using SISVAR 5.8 software, and by applying the "F" test at a 5% significance level, it was possible to observe the significant effect of the treatments. The means obtained for the performance parameters of the evaluated weeding systems were compared using Tukey's test at the 5% probability level.

Results and discussion

Conceptual design and choice of the variant with the highest project feasibility index

In the developed conceptual project, necessary requirements were determined to meet the requirements of the solution. According to Pahl et al. (2005), the project could be considered as innovative because new tasks are performed by new solution principles or a new combination of already known solution principles.

The prototype was defined as a mechanism capable of uprooting different weed species in vegetable beds. Given the above, the development of the prototype focused on the impact on acquisition and maintenance costs for producers as well as the gain in efficiency and operational capacity compared to manual activities.

As shown in Figure 1, the developed morphological matrix allowed the combination of subfunctions in different ways to obtain a greater number of solutions suitable for the project. Given the combinations, together with the subfunction solutions, a list of variants was created. After conducting the survey of solutions and subfunctions, five variants were selected to evaluate and detail the aspects, allowing the identification of the positive and negative points of the proposed solutions. Thus, Variant 1 (F1S3 F2S3 F3S1 F4S5 F5S4); Variant 2 (F1S1 F2S2 F3S3 F4S5 F5S5); Variant 3 (F1S4 F2S5 F3S4 F4S4 F5S2); Variant 4 (F1S5 F2S4 F3S3 F4S4 F5S5); and Variant 5 (F1S2 F2S1 F3S2 F4S4 F5S2) were defined.

According to Table 1, the assignment of scores to the presented variants indicated the project's feasibility index, where it can be seen that Variant 3 yielded the best result, thus chosen for the subsequent stages of prototype development. Therefore, the conceptual design for the prototype of a mechanism to remove weeds from between rows consists of cylinders fixed to the chassis by axles and in tangential contact. Considering the reverse rotation of the cylinders, it is assumed that the weeds will be caught between them and consequently pulled from the soil.

	Solution				
Subfunction	S1	S2	S3	S4	S5
F1-Uproot plant	Adhesive mat	Toothed rollers	Claws	Smooth rollers	Clamp
F2- Transport plant	Manual	Belts	Fans	Mechanical arms	Brushes
F3- Support machine	Wheels	Roller system	Tractor	Ski system	
F4- Provide energy	Gearing	Pedal mechanism	Animal	Eletric motor	Engine
F5- Move machine	Animal	Human trait	Eletric motor	Tractor	Engine

Figure 1. Morphological matrix with sub-functions (Sx) and solutions of the functions (Fx).

Table 1. Final score and project feasibility index of the weeder variants after weighting by evaluation criteria.

		F1Sx	F2Sx	F3Sx	F4Sx	F5Sx	Total Score	PVI
Variant 1	Ts	6	9	8	10	7	40	0.98
	Es	7	7	7	10	10	41	
Variant 2	Ts	7	9	7	10	10	43	0.93
	Es	8	8	10	10	10	46	
Variant 3	Ts	9	10	8	9	9	45	1.22
	Es	6	7	9	9	6	37	
Variant 4	Ts	7	8	7	9	10	41	0.87
	Es	8	10	10	9	10	47	
Variant 5	Ts	8	6	9	9	9	41	1.05
	Es	9	6	9	9	6	39	

Ts-Technical Score; Es-Economic Score and PVI- Project Viability Index.

For this purpose, it will be necessary for the cylinders to remain close and adjusted sufficiently to prevent slipping and tension buildup as weeds become trapped between them during operation. This was achieved with a tension-regulating mechanism between the cylinders, similar to a spring, designed to press one cylinder against the other and ensure the necessary contact adjustment.

The movement of the rollers would be driven by an electric motor connected and operated by the operator, without any additional traction support, and designed to glide on a ski-like base. Additionally, there was a cleaning mechanism involving a brush rotating above the rollers.

Prototype description

In developing the virtual prototype, all technical information was defined, respecting the concepts outlined in variant 3. The chassis was designed and composed of aluminum sheets where all other machine components would be mounted (shafts, cylinders, power source, mechanism for collecting and transporting weeds, and opening mechanism). Additionally, the chassis has three holes and a semicircular groove for the movement of one of the rollers and the fixation of four shafts.

Conceptually, the power supply needed to operate the prototype would come from a 12V electric motor mounted on the machine chassis and connected to a battery housed in a backpack. The rotation of the engine to the main shaft would be transmitted by a worm screw and a gear. The movement of the electric motor enables activation from the drive shaft to the cylinder and cleaning of the brush shaft through gears.

To achieve rotation of the cylinder shaft in two different directions, clockwise and counterclockwise, four gears would be used: two with an outer diameter of 36 teeth, and two with an outer diameter of 24 teeth. Each gear would be fixed to a threaded shaft connected to the drive on the roller and brush shafts, through its centre and fixed on both sides by nuts and counter nuts.

The opening mechanism was designed to separate the rollers for the thicker materials passage that could jam the machine, such as clods and stones. A spring was responsible for pulling the movable roller towards the fixed roller, increasing friction for weed removal. The support structure of the weeder was designed in aluminum, resembling a ski base. This structure chosen was to prevent soil compaction while ensuring ease of movement during operation.

The cleaning mechanism was designed with a brush rotating in the same direction as the front roller, allowing weeds pulled by the prototype to be removed from the rollers and transported to a storage location for later disposal. The control mechanism consists of an aluminum bar fixed to the chassis with lateral movement limiters and a rotation limiter to lift the machine without spinning uncontrollably. With all mechanisms defined as shown in Figure 2, the virtual project was completed.

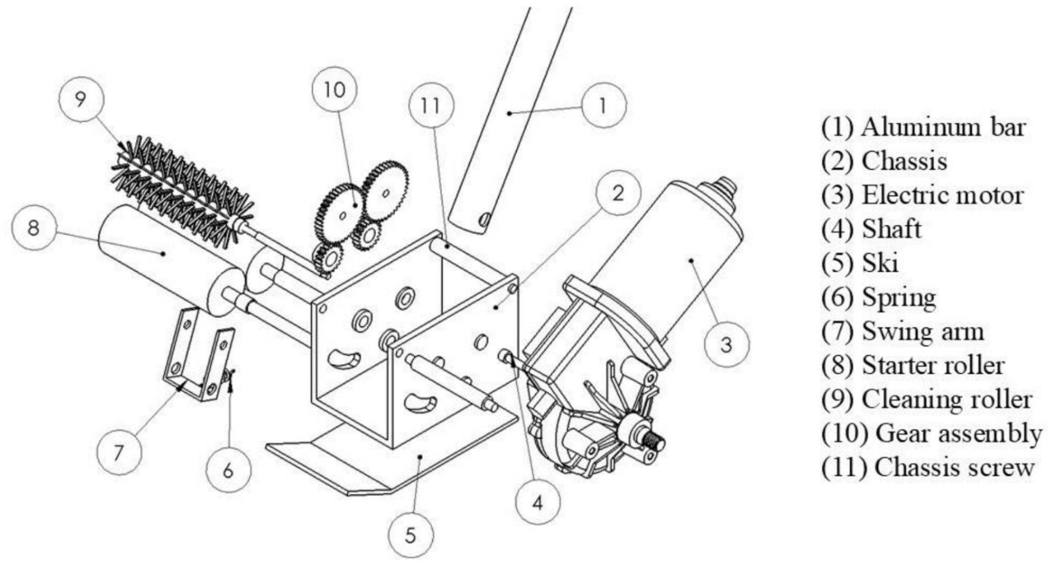

Figure 2. Virtual prototype design for the removal of invasive plants in vegetable beds.

After obtaining the conceptual and virtual design, the construction phase of the prototype began. Initially, the aluminum chassis was constructed with a thickness of (0.006 m), consisting of three separate parts (two sides and one base). The sides were fastened to the base using two M6 screws, two spring pins, and one M2 screw on each side. Three through-holes of (0.006 m) diameter were drilled on each side using a column drill with a (0.06 m) diameter and (0.025 m) long slot. Additionally, a non-through hole was drilled on its base to secure the spring for the roller opening mechanism.

As shown in Figure 3a, the rotation transmission mechanism consisted of two plastic gears with outer diameters of (0.039 m) and 36 teeth and two with outer diameters of (0.027 m) and 24 teeth. The gears were fixed to a shaft made of M5 threaded rod. M5 nuts and counter nuts were used to fix the gears and opening mechanism to the shafts and shafts to the chassis. A total of 24 M5 nuts were used.

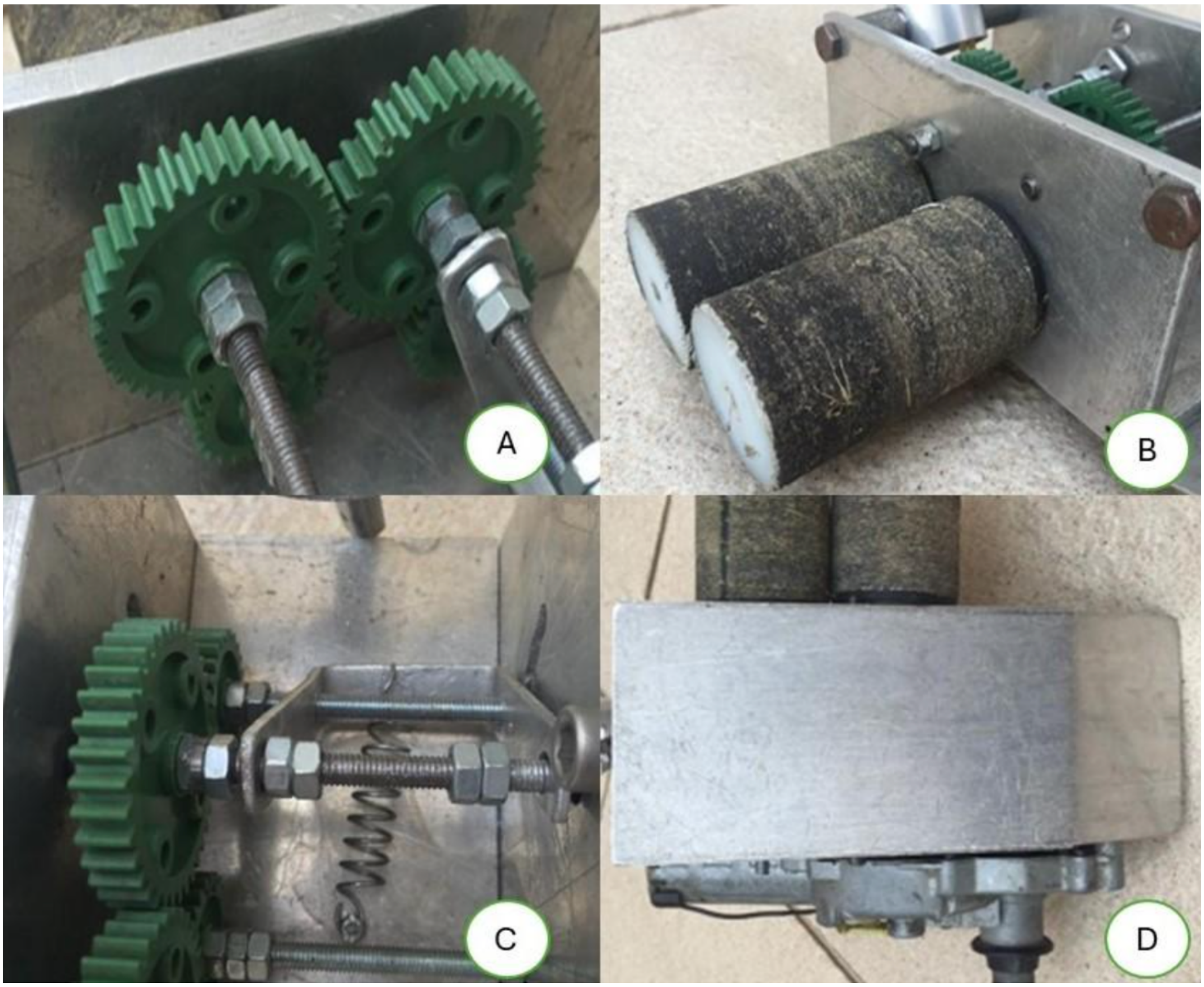

Figure 3. Transmission (a), removal (b), opening (c), and support (d) mechanisms built into the physical prototype.

For the removal mechanism, two nylon rollers were manufactured on the lathe with a diameter of (0.04 m) and a length of (0.085 m). The rollers have through-holes with a diameter of 0.005 m in their centers to fix the transmission shafts. As shown in Figure 3b, the rollers were coated with wood sandpaper to provide greater grip strength and enhance weed removal.

The opening mechanism, as shown in Figure 3c, was constructed with an aluminum plate of (0.002 m) and (0.01 m) in a “U” shape, with two holes with a diameter of (0.005 m) on each side of the plate to allow the passage of the shafts. A tensioned spring was fixed to connect the structure and prototype chassis.

According to Figure 3d, the support structure of the prototype was made of aluminum and mounted on an aluminum base (0.003 m) thick, (0.09 m) wide, and (0.19 m) long. At the tip of the developed machine, a bend was made in the plate at an angle of (30°) to prevent soil from entering the machine as it slid.

The control mechanism was developed with a (0.002 m) thick, (0.035 m) in diameter, and 1m in length aluminum tube. A through-hole of (0.006 m) was created at one end of the tube to fix it to the chassis. Two horizontal movement limiters are installed on the sides of the tube. An aluminum plate (0.06 m) was fixed to the same end of the tube through a pop rivet and bent at an angle of (45°) to limit the movement in the rotation direction of the shaft. The aluminum plate served as a physical barrier that touched the base of the chassis.

After manufacturing all parts and assembling the components individually, a physical prototype was assembled, as shown in Figure 4. It is worth noting that the physical prototype did not feature a cleaning system because the presence of the brush hindered the movement of the rollers, requiring an even higher torque from the motor, a factor that could not be achieved with the motor used in the project.

Figure 4. Physical prototype developed for mechanized weeding of vegetable beds.

Prototype performance evaluation under field conditions

Among the evaluated performance parameters, there was a significant difference between the two types of weed management systems assessed (Table 2). Based on the results, both the total removal efficiency (%) and the efficiency of removal of plants with roots (%) showed a significant difference between the treatments, with the manual weeding system proving to be more efficient in the control.

Table 2. Operational performance and weed removal efficiencies of the evaluated weeding systems

	Total Removal efficiency (%)	**Efficiency of removal plants (%)**	**Operational capacity (m^2 min^{-1})**
Prototype	70.3 b	66.3 b	0.69 a
Manual weeding	96.4 a	86.6 a	0.34 b
Standard deviation	14.15	10.73	0.19
Coefficient of Variation	16.98	14.04	27.26
Standard error	4.08	3.10	0.05

For each performance parameter, means followed by different letters indicate significant differences between weeding systems (Tukey test, $p < 0.05$).

According to Hussain et al. (2018), the development of automatic weeding machines has yielded increasingly satisfactory weed control results. Several authors, such as Liu et al. (2023) and Zawada et al. (2023), achieved mechanical removal efficiencies in weed control ranging from 70 to 80%.

In developing a mechanical weeder and evaluating the yield and quality of rice production, Jiao et al. (2022) obtained mechanical removal efficiencies ranging from 73.8% to 96.6%, indicating that this is an efficient process to replace the application of herbicides. Considering the results obtained with more complex and technologically advanced designs, the developed prototype achieved a removal efficiency of 70.3%, which is considered satisfactory, particularly when evaluating its application for small-scale farmers.

When evaluating the operational work capacity, the results indicate that the developed prototype allowed for a 49.3% increase in the worked area and a consequent reduction in time for the operation compared to manual weeding. Fennimore et al. (2016) mentioned the need to develop efficient technologies and machines that increase weed control in crops such as flowers and vegetables.

Adetola (2019), addressing the mechanical control of weeds and demonstrating the perspectives, performance, and limitations of different machine projects, found removal efficiency averages between 63.5 to 95% and operational capacity of 0.004 – 33.3 m^2 min^{-1}.

Kumar et al. (2013) evaluated the operational and ergonomic performance of two manual machines developed for mechanical weeding in rice cultivation, observing operational capacities of up to 3.75 m^2 min^{-1} and 77.1% for the models studied. Additionally, the authors mentioned that operational efficiency is directly related to the action of the machine's cutting and pulling mechanisms and the effort exerted by the operator.

Bhavin et al. (2016), while evaluating the performance of a single-row manually operated weeder for the peanut crop, found that the developed design could operate at depths of up to 4 cm, with an operational capacity of 4.75 m^2 min^{-1} and a maximum weeding efficiency of 80.4%.

Ragesh et al. (2018) evaluated a modified motorized weeder compared to other conventional weeding systems in upland rice cultivation and achieved operational capacities of 1.66 and 1.83 m^2 min^{-1}, respectively, for controls performed at 20 and 45 days after sowing.

Saleh & Suleiman (2021), when developing a manually pushed device for mechanical weed control, achieved a machine designed to be lightweight, allowing for 84.7% weed removal efficiency and an effective capacity of 2.15 m^2 min^{-1}, which, according to the authors, required less effort from the farmer compared to traditional tools like the hoe.

In a study conducted to design and evaluate a multi-row weeder (MRW) powered by a two-wheeled power tiller for effective weed control in wheat production fields, Saha et al. (2021) achieved an effective weed management design capable of performing faster weed control in wheat, with an operational capacity of 3.83 and 6.66 m^2 min^{-1} for the evaluated periods.

Guru et al. (2018) developed a single-row motorized weeding machine for inter-row weeding in rainfed crops and achieved an operational capacity of 4.28 m^2 min^{-1} and weed removal efficiency of 61.53%, which is similar to the results of the present study. Additionally, the authors noted that the developed machine allowed for cost reduction and reduced labor demand compared with the traditional methods evaluated.

According to Silva & Chabaribery (2006), manual weeding systems, although efficient, have low productivity and high costs owing to labor availability, which can represent up to 25% of the total operational cost. Furthermore, mechanical weeding can achieve higher weed control efficiencies than chemical methods, which are considered expensive and hazardous to human health (Annamanai et al., 2020).

Considering the above, with the greater adoption of organic production systems and increasing restrictions on the use of herbicides, new research for the development of more efficient machines is being conducted, and their use is increasingly encouraged in association with conservation practices, such as intercropping and the use of cover crops, which can reduce weed control costs (Silva et al., 2012; Melander et al., 2018).

According to Naruhn et al. (2021), the current major challenge in the use of mechanical weeding is to make it more precise between and within crop rows, either through the use of robotic technologies, sensors, or designs that demonstrate operational performance and uprooting efficiency.

Devanathana et al. (2021) describes that recent advancements in mechanical weed control methods seek innovative solutions in the design and materials used for constructing machines, thus aiming to reduce project costs. Thus, the tools used for creating the concepts and mechanisms of the developed prototype resulted in a machine with a unique and innovative concept.

Conclusions

Based on the results obtained, the applied project methodology enables the development of a weeding prototype capable of removing invasive plants from vegetable beds. The creation of mechanism concepts made it possible to evaluate some possible variants, enabling the choice of a unique and innovative concept for the developed machine, resulting in the filing of the patent for the weeding variants for the mechanical management of invasive plants in vegetable beds.

The operational performance of the prototype was adequate according to the literature, enabling mechanical removal of the invaders. Therefore, it is possible to affirm that the developed prototype can be an efficient tool, especially for small vegetable producers, once and for all inserting this producer into more productive practices and production processes.

Data availability: Not applicable.

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Authors' contributions: Marcus V. M. Oliveira: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **João P. B. Cunha:** Formal analysis, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Rodrigo T. C. Oliveira:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Murilo M. de Barros:** Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing. **Anderson G. Costa:** Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing.

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