EXPERIMENTAL RESEARCH REGARDING THE ACHIEVEMENT OF AN EQUIPMENT DESIGNED FOR CHOPPING WOODY WASTE
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CERCETĂRI EXPERIMENTALE PRIVIND REALIZAREA UNUI ECHIPAMENT DESTINAT TOCĂRII RESTURILOR VEGETALE LEMNOASE

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ABSTRACT
This article presents the results obtained through experimental research carried out with a machine for shredding woody plant residues (twigs, vine ropes), residues obtained from dry or green cuttings, in fruit or wine plantations. The obtained shredding is intended for utilization in the form of compost or biofuel (pellet type). The machine was designed and made by a group of researchers from INMA Bucharest, with the aim of developing the machine system made available to farmers, for mechanized work in small and medium-sized fruit plantations. The sizes of the fractions of the wood fragments resulting from the chopping process, their humidity and volumetric weight were determined. Using as raw material greener or drier branches, with dimensions between 10-45 mm, with an adjustment of the chopping drum at an average speed of 1400 rpm and an average speed of the conveyor chain of 0.425 m/s, wood chips with different sizes between 4-16 mm were obtained, the proportions varying from 13% to 16%. The average working capacity of the equipment was approx. 14.2 mc/h. Research will continue to determine the energy indices of the machine designed and made at INMA Bucharest, and the results will be presented in another article.

REZUMAT
Acest articol prezintă rezultatele obţinute în cadrul unor cercetări experimentale efectuate cu o maşina de tocat resturi vegetale lemnoase (crengi, coarde de viţă de vie), resturi obţinute din tăierile în uscat sau în verde, în plantațiile pomicole sau viticole. Tocătura obținută este destinată valorificării sub formă de compost sau biocombustibil (de tip peleţi). Maşina a fost proiectată şi realizată de către un grup de cercetători din INMA București, cu scopul dezvoltării sistemei de mașini pusă la dispoziția fermierilor, pentru efectuarea de lucrări mecanizate în plantațiile pomicole de dimensiuni mici şi mijlocii. Au fost determinate dimensiunile fractiilor lemnoase rezultate în urma procesului de tocare, umiditatea acestora şi masa volumică. Utilizând ca materie primă crengi mai verzi sau mai uscate, cu dimensiuni cuprinse între 10-45 mm, cu un reglaj al tamburului de tocare la o turație medie a de 1400 rot/min şi la o viteza medie de avans a benzii transportoare de cca.0.425 m/s, s-a obținut o tocătură lemnoasă cu diferite dimensiuni cuprinse între 4 şi 16 mm, proporțiile variind de la 13% la 16%. Capacitatea medie de lucru a echipamentului a fost de cca.14.2 mc/h. Cercetările vor continu pentru a determina indicii energetici ai maşinii proiectată şi realizata la INMA Bucureşti, iar rezultatele vor fi prezentate într-un alt articol.

INTRODUCTION
On a global level, as mentioned in the Green Deal pact, there are preoccupations for the recovery of waste in order to reduce pollution, to maintain a green planet, to reduce the carbon footprint and to reach in 2050 the target of 0 (zero) polluting emissions. Reducing energy consumption is another objective for which in-depth research is being done, in order to use renewable energy sources instead of conventional ones, which have been used indiscriminately and which can be exhausted, so the planet and the entire humanity would suffer. For these reasons, research is being carried out in all areas that could bring a favourable contribution to the fulfilment of these objectives (*Jasinskas et al, 2017*; *Kopac et al, 2003; Caba, 2019)*.

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Biomasses from agriculture could be used as a dry fuel, when harvested at maturity with about 85% dry matter by baling or chopping, or as a humid fuel with up to 60% dry matter, when harvested before maturity with a chopper, conserved by ensiling and mechanical dehydration before thermic use. To characterize both fuels from different crops chopped with a theoretical cutting length of 4 mm, particle-size-distribution, bulk density and an apparent density as well as nutrient contents and ash fusibility are determined. Wood chips (10 and 20 mm cutting length) have been investigated by *Stulpnagel, (1998)*.

Every year, in orchard plantations or in vineyards, pruning branches in autumn or spring, can offer biomass which can be chopped using special machines. To be profitable, these machines must have high-performances, in order to obtain wood chips at a low cost.

Chopped woody residues can be used to obtain compost or pellets. Pellets are a source of alternative energy and can be obtained from agricultural and forestry materials such as: sawdust, branches, scraps of boards or other wooden scraps, leaves, straw, sunflower or corn stalks, soybeans, etc. The pellet production line also includes biomass chopping or shredding equipment (*Mady, 2015*). The importance of using pellets has determined the performance of numerous researches both on how to obtain them and on the benefits of using them. In the last period, wood pellets are increasingly used, because they are a less polluting source of energy, having less greenhouse gas emissions, and also a renewable fuel, replacing fossil fuels (*Jasinskas et al., 2017; Nedelcu A., 2020; Supin, 2015; Gageanu, 2019)*.

Hamzah et al., (2017), analysed the wood pellets and torrefied wood pellets (named black pellets) as compared to coal and the conclusion was that torrefaction improves the fuel properties of wood pellet similar to coal. Torrefied biomass is more brittle than raw biomass and has a higher carbon content.

Compost is considered one of the best natural and organic fertilizers, obtained by decomposing plant biomass, and chopped branches can also be part of its composition (*Ciuperca et al., 2022; Lixandru et al., 2021; Stefan et al, 2020; Stefan et al, 2021)*

Some researchers have carried out experimental research of a chopper equipment for shredding residual wood branches, in order to improve its technical and technological performance. For this purpose, they implemented sensors and transducers on the equipment to record the evolution of the mechanical and hydraulic parameters. (*Cristescu et al., 2021)*.

Researchers from Poland have developed and tested an innovative system for controlling the variable feeding of equipment for chopping woody plant residues with low power engine. Fuel consumption in the case of the pilot system equipped with an adaptive feeding system was optimized, compared to the constant feeding system. The favourable effects of the tested systems have been demonstrated *(Warguła Łukasz et al, 2022). Wargula et al., (2018),* designed and realized a research stand that allowed both the analysis of the constructive and functional characteristics of the chopper, as well as the evaluation of the wood chopping process. The research carried out by this research team was valuable because it brought important information regarding the factors and their influence on the wood chips shape produced after chopping, as well as the influence on the energy consumption used in the chopping process. Important conclusions could be drawn that lead to the improvement of the work process of this equipment, taking into account that it is influenced by the orthotropic properties of the chopped material, which has an inhomogeneous structure.

Lyashenko et al., (2022), tested a wood branch chopper under specific conditions and obtained certain results that made it possible to provide instructions for its operation as well as its adaptation to the conditions of small plantations in individual fruit orchard.

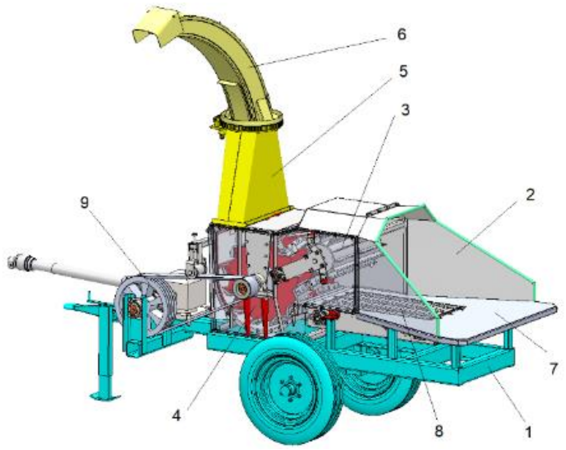
Taking into account the importance of research in order to diversify and improve machinery for chopping wood waste, especially branches, researchers from INMA Bucharest have proposed a technology and equipment, the use of which will lead to obtaining wood chips, a technology that will contribute to reducing pollution environment and use wood chips as an organic fertilizer or mulch.

The main objectives of this research are: to justify the technology of using tree branch waste; to choose the optimal working parameters for the developed chipper, which is used in the technological process of chopping tree branches and to analyze the effect of the forward speed of the conveyor and the rotation speed of the chopping rotor on the size of wood chips.

MATERIALS AND METHODS

The research carried out had as preliminary stages the analysis of the state of the art worldwide, followed by the design and realization of the experimental model for the equipment designed to chopp wood tree branches, acronym TRL (*Popa et al, 2022a; Popa at al, 2022b)*.

The existing research infrastructure within the Research-Development-Innovation laboratories, the Execution Section and the Testing Department was used for the realization and the execution of the project, as well as for the experiments (*https://www.erris.gov.ro/System-of-designing-execution-and-optimising-the-technical-equipment-and-technologies*; *https://www.erris.gov.ro/research-infrastructure-for-agriculture-forestry-and-food-industry*). The design was carried out using SolidWorks, 3D design software, which made it possible to obtain the 2D execution documentation and manufacture the experimental model within the execution department of the research institute. Using this software the time for development was reduced, and the quality of the final product was higher. Tests under real working conditions, by simulation of the working process have been done. 3D Solidworks ensure product quality while reducing prototyping and physical testing costs. The main assemblies of the machine are presented in figure 1.



a) Machine Design

b) Experimental model

Fig. 1 - Technical equipment for wood waste chopping

1 – infrastructure; 2 – assembled housing; 3 – wood drive drum; 4 – chopping drum; 5 – intermediate section; 6 – material discharge basket; 7 – loading platform; 8 – conveyor chain; 9 – mechanical transmission; 10 – hydraulic transmission

(Source: Popa et al., 2022b)

The equipment consists of welded assemblies and elements in series production (gear motor, transmission chains, bearings, wheels, hydraulic cylinders, hydraulic components, removable fasteners: screws, nuts, washers, Grower flat washers and so on). The “core” of the equipment is the chopping drum, which is different from the constructive solutions currently in production. The knives are disposed staggered, to improve the cutting process. The knives are made by a special steel, HARDOX 500, characterized by very good resistance to shocks and deformations.

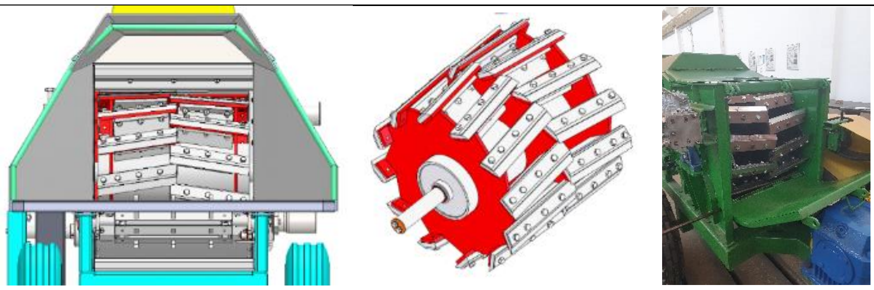


Fig. 2 - Chopping drum with staggered knives

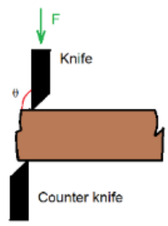


Fig. 3 - Chopping process

The chopper is also equipped with a counter-knife, realized by the same special steel. Together they work like scissors, under the acting force and inertia force. The cutting of the branches is done transversely, the size of the chips depending on the speed of the scraper conveyor, of the type with scrapers arranged on chains with special sprockets.

Before the experiments, the machine was put into operation empty, so that the preliminary adjustments could be made. Experimental research was carried out in November 2022, on the research platform in the INMA enclosure. The purpose of the research was the analysis of the degree of shredding of chopped branches, at certain functional parameters of the machine. The resistant moment was also registered, when the machine worked without load and under load.

To register the resistent effort at the chopping drum, a data acquisition system type MGCplus – HBM (Hottinger-Baldwin-Messtechnik)(Fig.4a) was used. A moment transducer type T 4WA -S3 (Fig.4b), a connecting system interface (Fig.4c), an acquired data setup interface (fig.4d) and a softwere CatmanEasy for data acquisition were used.

c) d) c) d)

Fig. 4 – Data acquisition system

Rotational speeds of the feed drum and of the chopper drum have been measured using a digital tachometer (Fig.5), which allows the operator to make revolutions per minute (RPM's) and speed (m/min) measurements. It offers a high accuracy (0.005%) up to 1 m distance (without contact).

A vibratory sieve shaker AS 200 Basic was used to separate the material into fractions (Fig.6). (*https://www.retsch.com/products/sieving/sieve-shakers/as-200-tap/*). Each vibratory sieve shaker of the series AS 200 is equipped with an electromagnetic drive that is patented by RETSCH (EP 0642844). This drive produces a 3D throwing motion that moves the product to be sieved equally over the whole sieving surface.

The advantage: high stress capacity, extremely smooth operation and short sieving times with high separation efficiency. The moisture and volumicetric weight were also analysed, using a Moisture Analyzer, MB120 AM (*https://us.ohaus.com/en-US/Products/Balances-Scales/Moisture-Analyzers/MB45/Moisture-Analyzer-MB45-AM*) (Fig.7)

Fig. 5 – Digital tachometer

Fig. 6 – Vibratory sieve shaker AS 200 Basic

Fig. 7 – Moisture analyzer

Volumetric weight (ρ_v) is a property of vegetable materials, in the form of chopped or ground, which defines the weight of fragments (m_f) of chopped plants related to the whole volume they occupy (relation 1). The total volume (V_t) occupied consists of the volume of the fragments and the volume of the voids between the fragments.

$$\rho_v = \frac{m_f}{V_t} \quad [\text{kg/m}^3] \tag{1}$$

RESULTS AND DISCUSSIONS

The experiments were performed using branches obtained from trees, green and dry branches, having dimensions between 10-45 mm (Fig.8a,b,c).

a)

b) c)

Fig. 8 – The woody plant material used for experiments

Feeding drum rotational speed was measured and noted, as it can be seen in Fig.9. The rotational speed was also measured for the drum chopper. Feeding drum has been set using the hydraulic distributor and also a hydraulic drossel, and the quantity of chopped wood material was collected on a tarp and weighted.

The tests have been repeated for 3 speeds of the conveyor chain that supplies the shredder with wood branches, (0.425; 0.375; and 0.325 m/s), to check the behaviour of the shredder and the machine productivity.

Fig. 9 – Aspects during the work parameters recording

After the chopping process was finished, the chopped wood material was collected and the sizes of the chopped fractions, the volumetric weight of the material collected by dimensional fractions were determined and then the percentage of each dimensional fraction was calculated. The moisture content was determined. Three samples of 1500 g each, collected randomly, were analysed, precisely to ensure accuracy in the processing and interpretation of the results obtained from the experimental tests, and the data thus obtained were tabulated and graphically represented.

Fig. 10 – Aspects regarding the collected chopped material and its analysis

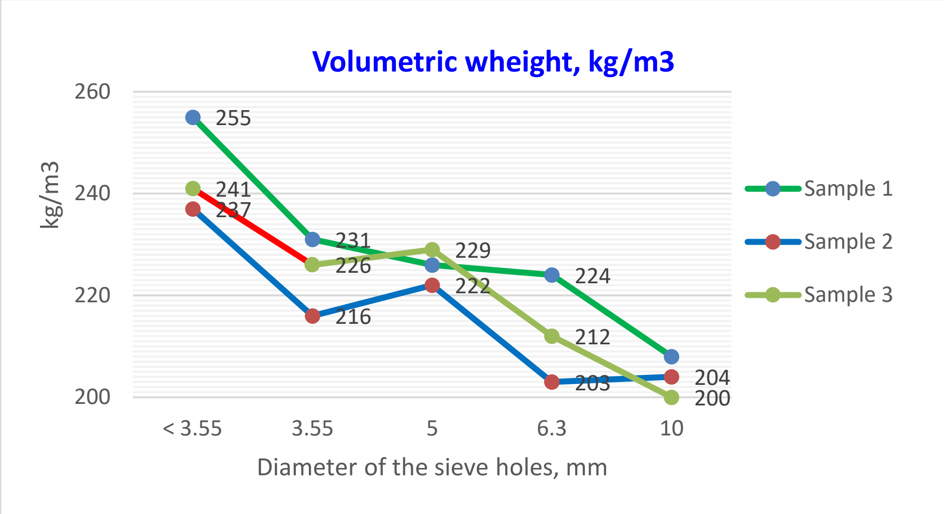
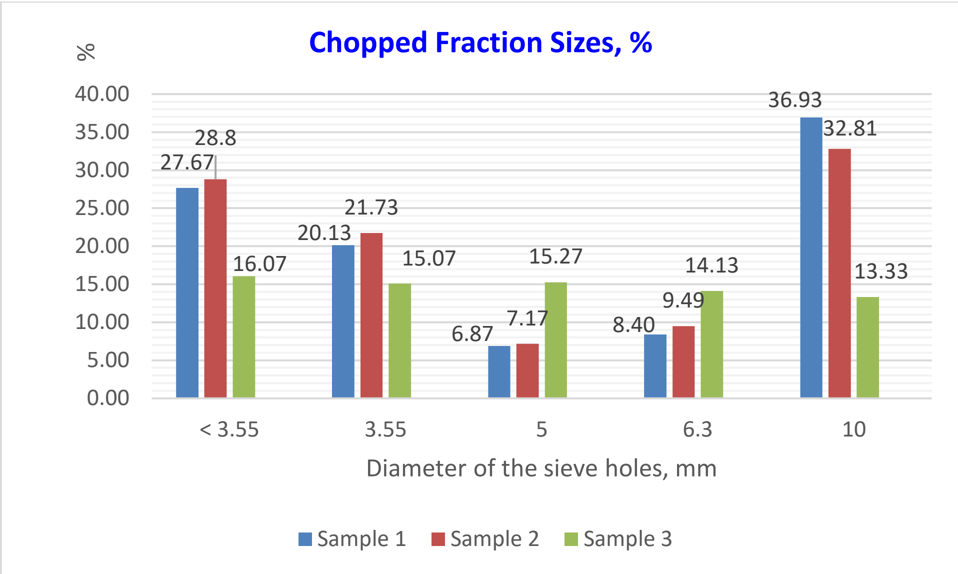
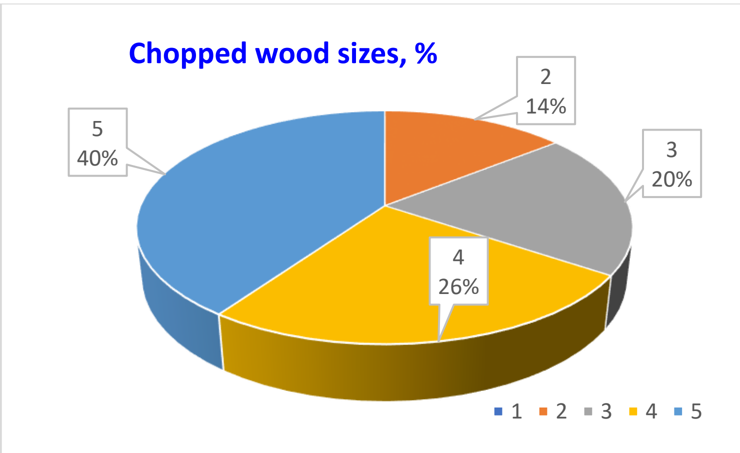


Fig. 12 – Volumetric weight for three samples



a) For each sample



b) Average of the three samples

Fig. 13 – Chopped wood fraction sizes, %

1 – Rejection < 3.55 mm; 2 – Ø3.55 sieve holes; 3— Ø5 sieve holes; 4 – Ø6.3 sieve holes; 5 - Ø10 sieve holes

The moisture content for each chopped wood fraction was determined and the results are presented in the following graphs.

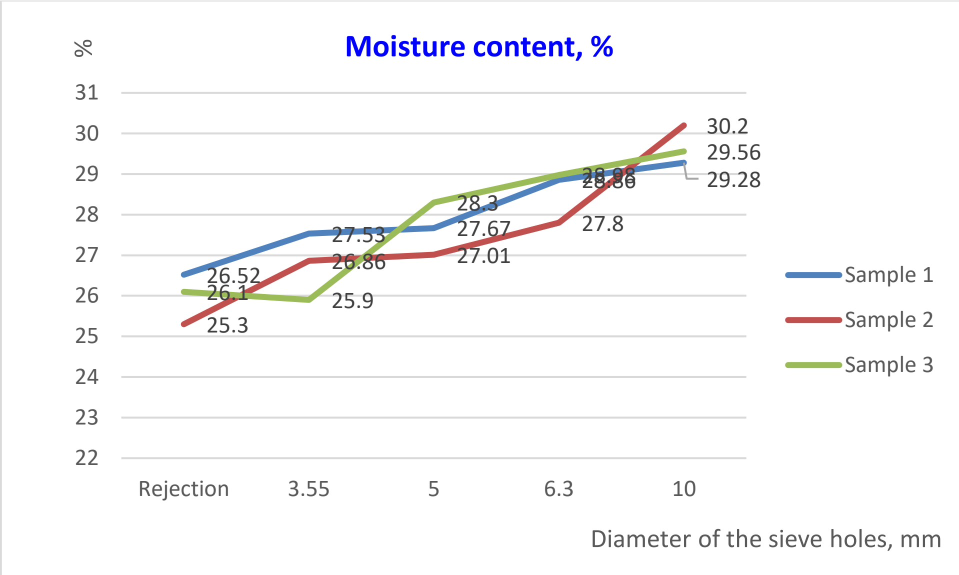
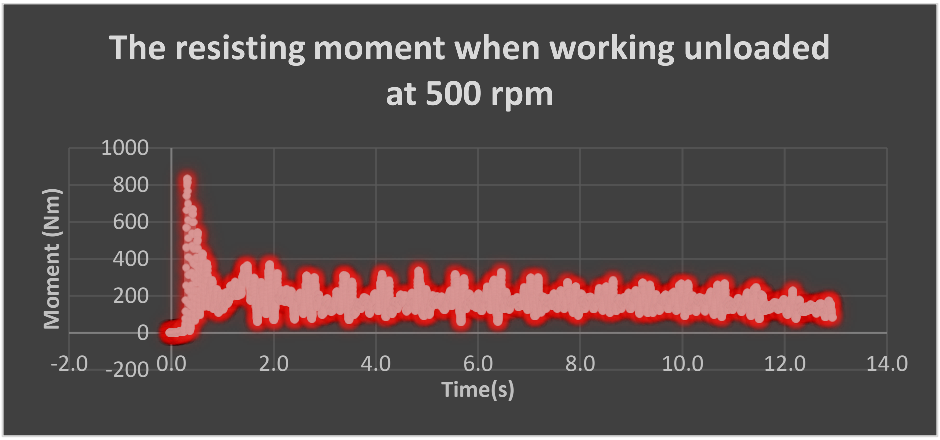


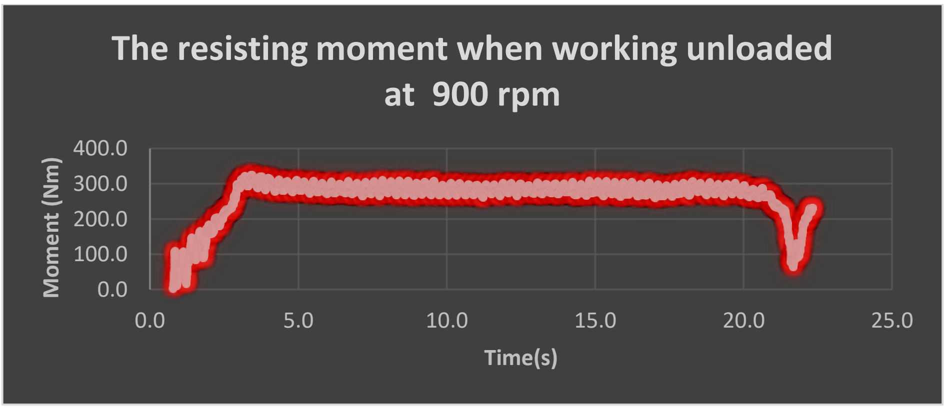
Fig. 14 – Moisture content for chopped wood fraction, %

Chopping drum is acted by a mechanical transmission, where the movement is taken from the tractor's power take-off shaft, through a cardan, then transmitted through a conical group to a belt transmission, whose multiplication ratio is i=3.2, and finally multiplying the rotational speed of the chopper.

The rotational speed of the chopping drum can be variable, depending on the nominal speed of the tractor engine. During these experiments, with the help of the equipment described in the previous chapter, the moment resistant to the chopping rotor was recorded for 4 nominal revolutions of the tractor engine (500 rpm; 900 rpm; 125 rpm and 1500 rpm). The determinations were made when the equipment works unloaded, and the research will be continued with the recording of the resistant moment when the equipment is loaded. The results are presented in the following graphs.

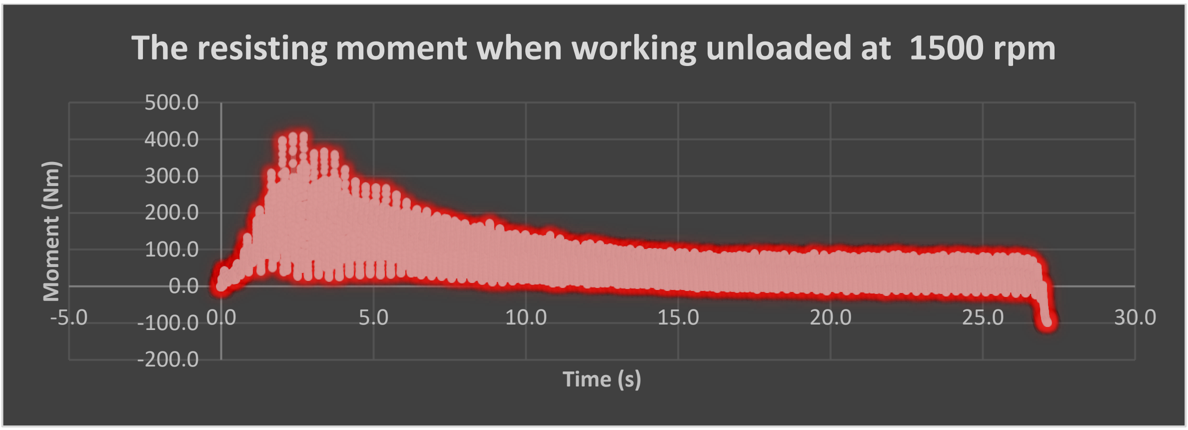


a)



b)

c)



d)

Fig. 15 – Resisting moment when working unloaded

Taking into consideration the experiments performed, a working average capacity was obtained, the values being as in Table 1.

Table 1

Working capacity of the equipment TRL-0

	Measure unit	Sample 1	Sample 2	Sample 3	**Average**
Working capacity	m^3/h	14.2	14.1	14.3	**14.2**

CONCLUSIONS

Not all chopping equipment provide good results if they are used in different conditions and using different wood residues and not all chopping machines are suitable for use on different plantations. It depends on the wood characteristics (moisture content, stress resistance, branch dimensions etc.).

Productivity depends a lot on the shape of the branches, the processed material not being homogeneous. The experiments performed did not aim at determining the performance characteristics of the car, but its functionality.

Research has shown that the machine produces wood chips with dimensions between 4 and 16 mm, those collected on sieves with a hole diameter of 3.55 mm as well as those collected on a sieve with a hole diameter of 10 mm being in a larger proportion than the other two.

The measurement of the moment resistant to the chopping rotor when working unloaded cannot measure the required power, for the optimization of the energy source in the aggregate, respectively the tractor engine power, but these data were collected to see the magnitude of the moment of inertia at start-up and the required surplus power for putting the machine into operation, in case of overload.

Other energetic and performance parameters of the machine will be carried out in a later stage of the research, when in-depth research will be undertaken, using several species of wood, and several variables will be set to different values (advance speed of the conveyor belt, rotation of the chopping rotor)

It is necessary to conclude that appropriate adjustments of the working parts of the machine can lead to obtaining the desired performances.

The productivity depends on the wood physical characteristics which also determines the resistance to cutting and can vary greatly. The moisture contend influences the cutting resistance. The drier the material is, the higher the cutting resistance. In this experiments poplar was used, which is relatively light in weight, has good strength in both tension and compression and provides rigidity, toughness and insulating properties.

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