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RESEARCH ARTICLE

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Mechanized harvesting and primary processing of *Calendula officinalis* L. inflorescences

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Abstract

Manual harvesting of marigold (*Calendula officinalis* L.) inflorescences results in superior quality, but requires enormous manpower. The objectives of the research were to examine the possibility of mechanized harvesting of marigold inflorescences by virtual rotating comb-type chamomile harvester, widely used in South Eastern Europe, and to develop the mechanical separator for the inflorescences from the harvested mass. The impact of coefficient *R*, ratio of the harvester's penetration into the inflorescences horizon and the width of inflorescences band (*i.e.* the average value of the highest and lowest inflorescences span) on the harvest yield, was tested first. Separation was performed by a bespoke separator that uses five cascades of oscillating sieves made of longitudinally situated rods. Influence of oscillation frequencies and rod distances on separation efficiency was investigated. It was found that, for coefficient *R* value of 1.3, an average of 97% of the total inflorescences yield can be harvested. The proportion of inflorescences with stem length up to 2 cm was 65% and 35% for stems over 2 cm. The result of mechanized harvest was the reduction in both the number of succeeding harvests and the yield, due to bud damages and elimination. The highest separation efficiency was obtained by using 2.7 Hz oscillation frequency and combination of 6/8 mm rods' distances in sieves. After three passes of the harvested mass through the device, approximately 92% of inflorescences were separated. Future investigations should be directed towards solving the issue of mechanical shortening of the inflorescences stems and evaluating the economic viability of mechanized harvesting within the proposed procedure.

Additional key words: marigold; virtual rotating comb; separation; sieves.

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Abbreviations used: h (tube height); h_{IHH} (inflorescences horizon height); h_{IW} (the width of inflorescences band): h_P (the depth of working device penetration into the inflorescences horizon); I_{H1} (indicator – percentage of the harvested inflorescences in the total inflorescences yield); I_{H2} (indicator – percentage of the harvested inflorescences in the total harvested mass); I_{H3} (indicator – the ratio of the mass of inflorescences with stem length up to 2 cm and the mass of inflorescences with stems longer than 2 cm); I_{S1} (indicator – the percentage of separated inflorescences); I_{S2} (indicator – ratio of the mass of inflorescences with stem length up to 2 cm and the mass of inflorescences with stems length over 2 cm, separated over the sieves); M_{HHa} (the total harvested plant mass per hectare); $M_{HI \leq 2}$ (the average mass of inflorescences samples with stem length ≤2 cm); $M_{HI > 2}$ (the average mass of inflorescences samples with stem length >2 cm); $M_{HI \leq 2ha}$ (the harvested mass of inflorescences per hectare with stem length ≤2 cm); $M_{HI > 2ha}$ (the harvested mass of inflorescences per hectare with stem length >2 cm); M_{HIha} (the total harvested mass of inflorescences per hectare); M_{HL} (the sum of inflorescences samples mass fallen to the ground and the unharvested ones, in g m^{-2}); M_{HLha} (total harvest losses of inflorescences per hectare); M_{OSI} (the total mass of inflorescences separated above the sieves calculated for the 2 cm stem length); $M_{OSI\leq 2}$ (the average mass of inflorescence samples above the sieves with stem length >2 cm); $M_{OSI > 2}$ (the average mass of inflorescences samples above the sieves with stem length >2 cm); M_{PSI} (the average mass of inflorescence samples which felled through the sieves); M_{SI} (the total mass of inflorescences contained in the processed material); M_{YIha} (the total mass of inflorescence yield per hectare); q (coefficient – the ratio of the mass of shortened stems and the mass of inflorescences samples with stem length >2 cm); R (coefficient – ratio of the penetration depth and the width of inflorescences band).

Introduction

Marigold (*Calendula officinalis* L.) is an annual herbaceous species, grown as ornamental and medicinal plant. This species is indigenous to central, eastern and south Europe and commonly cultivated in the North America, the Balkans, Eastern Europe, Germany and India (Khan *et al.*, 2011). Marigold is widely used in industry and medicine. Its antimicrobial and anti-human immunodeficiency virus actions have provoked great attention, increasing the interest for cultivation (Khalid & Teixeira da Silva, 2012).

Marigold is grown in crop rotation. Propagation is provided by direct sowing at the beginning of spring, with a row distance between 40 and 60 cm. The harvested inflorescences should be dried as soon as possible in order to prevent any quality reduction. The yield ranges from 800 to 1,500 kg of dried inflorescences per hectare, but can be even higher in favourable conditions (Kisgeci & Adamovic, 1994).

One of the problems of marigold production is a high cost of manual harvesting, *i.e.* picking of inflorescences, which is, during the flowering period, performed every 3 to 5 days. Hand - harvested inflorescences mostly belong to the best quality product, with stems shorter than 2 cm. However, the picker efficiency is around 4 kg h^{-1} of fresh mass (Veselinov *et al.*, 2008). Due to enormous labour requirements, manual harvesting is not profitable even in the developing countries. Hence the development of mechanized marigold harvesting is needed.

A few attempts to develop a specialized marigold harvester have been published. Willoughby *et al.* (2000) developed two different devices, both based on rotating pairs of picking fingers, but with different cleaning systems. The first uses retraction of fingers into cylinder and doffer brush, whereas the second utilises a rotor made of music instruments' wires for removal of inflorescences trapped by the picking fingers. Both machines are equipped with a separation band for the removal of admixtures. In both solutions, the picking efficiency was up to 80%. However, due to excessive losses (throwing off the inflorescences), the maximal efficiency of picked inflorescences was reduced to 60%. These solutions have not been introduced in practice.

Another attempt was done in Romania, by Jantschi *et al.* (2008). The prototypes of harvesting devices, one with stable tines and another with steel wires rotors, were tested. The testing method is not correctly described and the results are related only to the percentage of inflorescences recovery (in the article the term "recuperation" was used), which ranged from 60 to 80%.

There are some patented solutions that, according to claims, could be used for marigold inflorescences harvesting (Brown, 1996), but the application effects have not been reported.

According to Herold *et al.* (1989), Hecht *et al.* (1992), Dachler & Pelzmann (1999), Mohr (2002), Zimmer & Müller (2004) and Brabandt & Ehlert (2011), inflorescences of chamomile (*Matricaria recutita* L.), marigold, St. John's wort (*Hypericum perforatum* L.) and several other medicinal plants can be harvested by machines with the working device known as a rotating comb. Martinov & Adamovic (2002), Zimmer & Müller (2004), Martinov & Konstantinovic (2007) stated that the harvest of chamomile and pyrethrum (*Pyrethrum cinerariaefolium* Trev.) can be performed by the virtual rotating comb type harvester, by Brabandt & Ehlert (2011) named "rotating pin drum", with wide tines distance. The distance between tines is about 0.05 m and the comb effect is created by the drum rotation due to spiral tines setting. It is a simple low-cost solution and this type of harvester is widely applied in South Eastern Europe and many other regions. It has only one drawback - due to a progressive increase of losses at higher speeds, the working speed is limited to about 1.8 km h^{-1}.

Since marigold has a similar structure to chamomile, the presumption that marigold inflorescences can also be harvested by the same type of harvester, was confirmed by preliminary tests (Veselinov *et al.*, 2008). It was shown that considerable damage and elimination of buds occur, thus reducing the yield in the consequent harvests within one season. Furthermore, some harvested inflorescences have longer stems and harvested mass contains many admixtures. Consequently, additional processing of harvested mass is needed, similar to chamomile processing (Martinov & Oluski, 1998; Zimmer & Müller, 2004). Separation from admixtures should be performed before drying, whereas the stems shortening afterwards.

Marigold petals removal, *i.e.* threshing, was reported by Britton *et al.* (2001), and Armstrong *et al.* (2002). The threshing was performed between two oscillating plates in the first solution and within a special device integrated into a drum drier in the second solution. The reported results can not be applied here, because the complete inflorescences are treated as final products.

The research objectives were: (a) to test possibilities and efficiency of marigold inflorescences harvesting by exploiting an existing chamomile virtual rotating comb type harvester; (b) to develop and test a bespoke device for separation of inflorescences from stalks and leaves in the harvested mass.

Material and methods

Preliminary tests of harvest efficiency and operating parameters assessment were performed in 2008 and the measurements were finalized in 2009. Tests for separation of inflorescences from the harvested mass were performed in 2010 and the final measurements in 2011. The location for all tests and measurements was the Research Station of Hops, Sorghum and Medicinal Plants, in the vicinity of Novi Sad, Serbia.

Marigold var. 'Gelb orange', the variety most commonly grown in Serbia, was directly sown on a test plot of 0.6 ha, with a row width of 45 cm and crop density of 300,000 plants ha^{-1}. The plot was divided into six testing bands with equal number of plant rows. Common agricultural practices for marigold were applied. Marigold 'Gelb orange' is characterized by orange inflorescences, 5-8 cm in diameter, with multiple ligulate flowers. It contains a significant amount of carotenoids and phenolic compounds. This variety has a high regeneration ability (forming new inflorescences after each harvest), thus enabling several harvests in a single growing season.

Harvesting

Before each harvest, ten whole aboveground plants were randomly taken as samples (using a table of random numbers) from the whole plot, in order to determine their basic characteristics: the average width of inflorescences band, h_{IW} (Fig. 1-4), the moisture content and the percentage of inflorescences in the total above-ground plant mass. Also, the average inflorescences horizon height, h_{IHH} (Fig. 1-6), was determined by measuring the distance between the highest inflorescences and the ground, for these ten randomly selected plants. The average total mass of inflorescences yield per hectare, M_{YIha} (kg ha^{-1}), was calculated by adding the total average harvested mass of inflorescences, M_{HIha} (kg ha^{-1}) – mass of the inflorescences calculated for the 2 cm stem length, to the average loss of inflorescences M_{HLha} (kg ha^{-1}), for every single harvest.

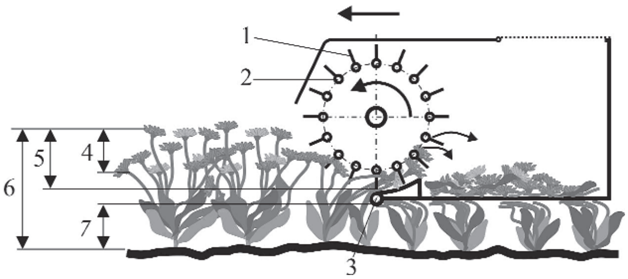

Figure 1. Schematics of the virtual rotating comb type harvester, with wide tines distance: 1, tine; 2, tines carrier; 3, round tube; 4, width of inflorescences band (h_{IW}); 5, depth of working device penetration into the inflorescences horizon (h_P); 6, inflorescences horizon height (h_{IHH}); 7, tube height (h).

Fig. 1 shows the virtual rotating comb type harvester with 1,200 mm working width and 720 mm picking cylinder diameter. The 75 mm long tines (Fig. 1-1) are placed on the sixteen tubular carriers (Fig. 1-2), with 50 mm spacing. On each following carrier, tines are longitudinally displaced, thus forming a spiral. When such drum is rotated, a virtual comb effect is achieved. A fixed round tube (Fig. 1-3) is placed at the distance of 10 mm from the tines tops. A container (1 m^3) for the harvested mass is situated behind the harvest cylinder.

For each measurement, the drum rotation frequency was 130 min^{-1} whereas the average working speed was 1.1 km h^{-1}. These values were defined as optimal during the preliminary testing. Harvests were performed every 15 to 20 days, after the formation of new inflorescences. Five harvests were performed during the first season and only four harvests during the second season, as a result of lower precipitation level, *i.e.* drought. Deflectors mounted in the front of the harvesting device enable harvest of three rows of plants in one pass (Fig. 2). This gives five recurrences (*i.e.* passes) within a harvest for an entire field.

During the first season, tests were performed in order to identify the optimal penetration depth of harvester working device into the inflorescences horizon. The harvests of the second season were aimed to repeat the test by using the best values of penetration depth.

In the first season harvests, different depths (in cm) of working device penetration into the inflorescences horizon h_P (Fig. 1-5) were applied. The ratio of the penetration depth and the width of inflorescences band is the coefficient R (unitless):

Figure 2. Tractor with mounted virtual rotating comb type harvester in the marigold inflorescences harvest

$$R(-) = \frac{h_P}{h_{IW}} \quad [1]$$

In each harvest of the first season, the value of the coefficient R was varied between 1.0 and 2.4, with the step increase of 0.1. The value of the coefficient R was tuned at the beginning of each recurrence, by setting the height h (cm) (Fig. 1-7) of the round tube in the harvester (Fig. 1-3), according to the equation:

$$h = h_{IHH} - (R \cdot h_{IW} + 4.5) \quad [2]$$

where the 4.5 cm offset is introduced due to the machine design characteristic, related to the round tube diameter (Fig. 1-3) and the tube distance from the tines.

After each recurrence, the total harvested plant mass was measured and M_{Hha} (kg ha^{-1}) value was determined. From the harvested mass, five 1 kg samples were randomly taken for a manual separation of inflorescences from stalks and leaves, by using a table of random numbers. Inflorescences in the samples were classified into two groups, according to stem length: below 2 cm and over 2 cm. The mass of each group was measured: $M_{HI\leq 2}$ – average mass of group with stem length ≤2 cm; $M_{HI>2}$, average mass of group with stem length >2 cm.

After the mass measurement, stems with length exceeding 2 cm were manually shortened to the length of 2 cm and the mass of cut leftovers was measured. The ratio of the mass of stems cut by shortening and the total harvested mass $M_{HI>2}$ is denoted as parameter q.

For each harvest, performed at defined area, three values were calculated: the harvested mass of inflorescences per hectare with stem length up to 2 cm, $M_{HI\leq 2ha}$; the mass of inflorescences per hectare with stem length over 2 cm, calculated for the 2 cm stem length, $M_{HI>2ha}$, and their sum expressed as the total harvested mass of inflorescences M_{HIha} (kg ha^{-1}):

$$M_{HIha} = M_{HI\leq 2ha} + M_{HI>2ha} \cdot (1 - q) \quad [3]$$

Losses, consisting of the inflorescences fallen to the ground and unharvested inflorescences, were measured on the same area. The harvested inflorescences fallen to the ground were collected manually and their mass was measured. Using the parameter q, the mass of inflorescences with stem length over 2 cm was recalculated to the mass referred to stems up to 2 cm long. Unharvested inflorescences were hand-picked (with stem lengths up to 2 cm) and their mass was also measured. The sum of these two values represents the total harvest losses M_{HL}. Finally, this value was calculated per hectare M_{HLha} and expressed in kg ha^{-1}.

Determination of the harvest efficiency is defined by following indicators:

— The percentage of the harvested inflorescences in the total inflorescences yield:

$$I_{H1}(\%) = \frac{M_{HIha}}{M_{YIha}} \cdot 100 \quad [4]$$

— The percentage of harvested inflorescences in the total harvested mass:

$$I_{H2}(\%) = \frac{M_{HIha}}{M_{Hha}} \cdot 100 \quad [5]$$

— The ratio of the mass of inflorescences with stem length up to 2 cm and the mass of inflorescences with stem longer than 2 cm:

$$I_{H3}(-) = \frac{M_{HI\leq 2ha}}{M_{HI>2ha}} \quad [6]$$

For each harvest in the second season, five recurrences were performed with the R value set to 1.3, which was identified as the best value after the first season. The measurement procedures were the same as in the first season.

Separation

The investigation of inflorescences separation from harvested stalks and leaves was performed by using a bespoke separation machine based on straw walker from a combine harvester. The design is conceptualised

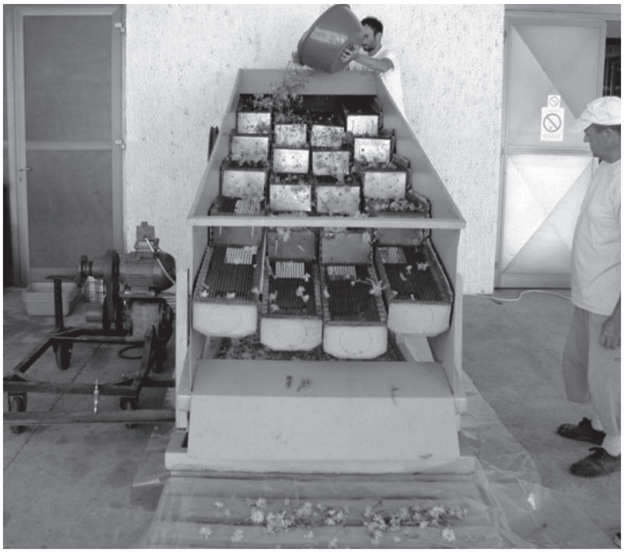

Figure 3. Device for separation of inflorescences from stalks and leaves

as the low-cost solution, with five-cascade sieves arranged in four parallel sections (Fig. 3), with the overall dimensions of 3 × 0.8 m. The separated inflorescences remain above the sieves whereas stalks and leaves fall through. The sieves are made of 4 mm diameter steel rods, situated longitudinally at selected distances. Originally, the rod's distances were 8 mm throughout the five cascades. Later, the rod's distances in the first two sieve cascades (from the feeding point of the processed material) were reduced to 6 mm, which is denoted as 6/8 mm sieve sets. The sieves in the first and in the last cascades are sloped by 10° whereas the sieves in the middle cascades are horizontal. The crankshaft eccentricity is 110 mm.

During the first season, the oscillating frequency of the separator was set to 2.5, 2.7 or 2.8 Hz. The best separation results were obtained using 2.7 Hz oscillating frequency and 6/8 mm combination sieves. Therefore, these configuration and frequency were used for separation testing during the second season, in which five repetitions were performed.

The total harvested plant mass was measured prior to each separation. After a single separation pass, the plant mass still contained plenty of unwanted stalks and leaves. Hence the plant mass was sieved two more times, in order to obtain the best possible separation.

From the total mass separated above the sieves after three passes, five 0.5 kg samples were randomly collected, by using a table of random numbers. From these samples, the remaining stalks and leaves were manually separated from inflorescences. Then, the inflorescences were classified into two groups according to their stem length - up to 2 cm and over 2 cm – and the mass of each group was measured. The average mass of each group, $M_{OSI\leq 2}$ and $M_{OSI>2}$, respectively, was calculated. The average mass value of class with stem length over 2 cm was calculated for the 2 cm stem length using parameter q, and the total mass of inflorescences separated by the sieves, referred to the 2 cm stem length, is expressed as:

$$M_{OSI} = M_{OSI\leq 2} + M_{OSI>2} \cdot (1-q) \quad [7]$$

Also, from the plant mass which fell through the sieves after three passes, five 0.5 kg samples were taken. Inflorescences which fell through the sieves usually were either stem-free or their stems were under 2 cm. They were separated by hand and their mass was measured. The average mass of these inflorescences, M_{PSI}, was calculated. The sum of the average mass values of inflorescences separated above the sieves and those which fell through the sieves represents the total mass of inflorescences contained in the input processed material, M_{SI}.

Determination of separation efficiency is defined by the following indicators:

— Percentage of the separated inflorescences:

$$I_{S1}(\%) = \frac{M_{OSI}}{M_{SI}} \cdot 100 \quad [8]$$

— Ratio of the mass of inflorescences with stem length up to 2 cm, $M_{OSI\leq 2}$, and the mass of inflorescences with stem length over 2 cm, $M_{OSI>2}$, separated over the sieves:

$$I_{S2}(-) = \frac{M_{OSI\leq 2}}{M_{OSI>2} \cdot (1-q)} \quad [9]$$

Statistical analysis of the efficiency of harvesting inflorescences and separation of marigold stems and leaves was executed according to the ANOVA models. A single factor of measured data is extracted and then its average value and standard deviation were calculated using Microsoft Office Excel – Analysis ToolPak.

Results and discussion

Basic characteristics of marigold plants in the first and the second season of the investigation, for each individual harvest, are shown in Table 1.

Table 1. Basic characteristics of marigold plants during the first and second season of the investigation. SD (standard deviation) is indicated in parenthesis

Harvest number	Average inflorescences horizon height h_{IHH}, cm	Average width of inflorescences band h_{IW}, cm	Percentage of inflorescences in plant mass, %	Average total inflorescences yield M_{YIha}, kg ha^{-1}
First season				
1	52 (3.6)	18 (3.9)	18.0 (2.5)	4,153 (270)
2	49 (3.9)	13 (2.8)	15.6 (1.1)	839 (42)
3	50 (4.1)	15 (4.1)	12.0 (0.7)	1,251 (65)
4	45 (6.9)	10 (2.9)	17.7 (2.4)	924 (54)
5	39 (6.4)	8 (2.2)	14.5 (1.0)	994 (68)
Second season				
1	46 (4.8)	15 (3.5)	15.0 (0.9)	1,230 (70)
2	43 (3.0)	12 (3.3)	13.7 (0.7)	1,710 (95)
3	33 (5.3)	10 (2.6)	11.1 (1.5)	1,366 (76)
4	32 (3.1)	10 (2.0)	14.3 (1.9)	1,536 (82)

Through each season, both the average inflorescence horizon height and the average width of inflorescence band show declining trends with the progressing harvests. Also, in both seasons, a downward trend of the percentage of inflorescences in the plant mass was noted until the third harvesting and then an increased re-growth occurred.

The average total inflorescences yield during both seasons had a stochastic character. Significantly the highest average total inflorescences yield was obtained during the first harvest in the first season (4,153 kg ha^{-1}, SD = 270 kg ha^{-1}), then decreased sharply during subsequent harvests. The fifth harvest brought only about 24% of the total yield of the first harvest (994 kg ha^{-1}, SD = 68 kg ha^{-1}). In the second season, the average total inflorescences yield varied between 1,230 and 1,710 kg ha^{-1} (SD = 95 kg ha^{-1}) due to weather conditions.

Harvesting

The ratio of the mass of cut leftovers of stems longer than 2 cm, in the total mass of harvested inflorescences with stem length exceeding 2 cm, during two harvest seasons, was $q = 0.336$ (SD = 0.076, significant at the $p \leq 0.05$ probability level).

Fig. 4 shows the changes of the indicators I_{H1}, I_{H2} and I_{H3} with the ratio of penetration depth indicator R. It can be seen that the highest average percentage of the harvested inflorescences mass M_{HIha} in the total inflorescences yield M_{Yha}, was $I_{H1} = 96.8\%$ (SD = 0.4%). It was achieved during the first harvest of the first season with value $R = 1.3$. The lowest value, $I_{H1} = 17.8\%$ (SD = 0.8%), occurred during the fifth harvest, with $R = 2.4$. The highest percentage of the total harvested mass of inflorescences M_{HIha} in the total harvested plant mass M_{Hha}, I_{H2}, was 58.3% (SD = 10.3%), achieved with $R = 2.0$, and the lowest was 22.3% (SD = 1.8%), obtained at $R = 2.4$. The highest value of the ratio of the mass of inflorescences with stem length up to 2 cm, $M_{HI\leq 2ha}$, and the average mass of inflorescences with stem length over 2 cm, $MHI_{>2ha}$, was $I_{H3} = 3.92$ (SD = 0.36), obtained with $R = 2.0$, whereas the lowest was $I_{H3} = 0.60$ (SD = 0.05), obtained with $R = 1.3$.

Significant total inflorescence losses, 72.2% (SD = 0.7%) and 82.2% (SD = 0.8%), with respect to the total inflorescences yield, took place when the coefficient R was 2.2 and 2.4, respectively. The highest percentage of losses represent unharvested inflorescences, 71.3% (SD = 0.9%) and 81.1% (SD = 1.2%), and inflorescences fallen to the ground during harvesting, 11.1% (SD = 0.6%) and 8.8% (SD = 0.9%), for coefficient R values of 2.2 and 2.4, respectively. Considerably lower losses of unharvested inflorescences were achieved with $R = 1.3$, amounting to 3.2% (SD = 0.4%) on average. An average of 54.7% (SD = 4.0%) of all losses were losses of inflorescences that have fallen to the ground for $R = 1.2$ but amounted the full 100% when the coefficient R was either 1.4 or 1.7, for not harvested losses.

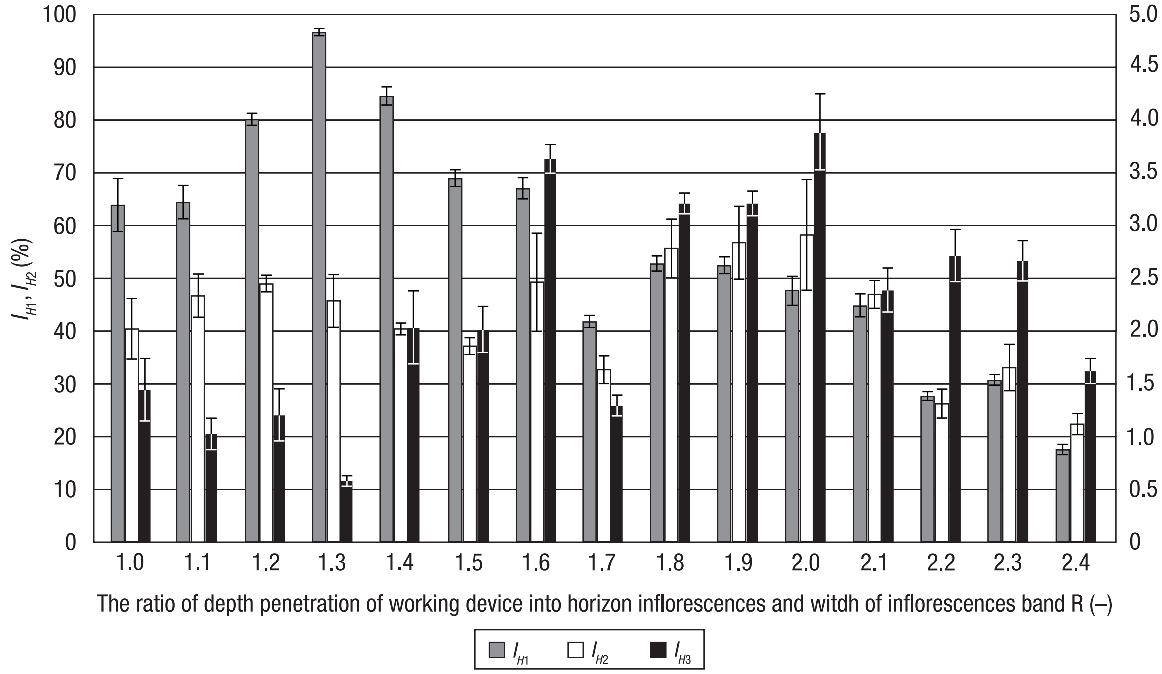

Figure 4. Indicators of harvesting efficiency I_{H1} (%), I_{H2} (%) and I_{H3} (unitless) for different values of coefficient R, in the first season of testing. Values in the histograms are significant at the $p \leq 0.05$ probability level. Bars on the histograms represent standard deviation.

During the second season of harvesting, only the optimal value of $R = 1.3$ was applied. In the four harvests, the obtained average values of harvest efficiency indicators were very consistent, hence the final results are expressed as their averages. They are as follows: $I_{H1} = 90.4\%$ (SD = 0.9%), $I_{H2} = 30.8\%$ (SD = 6.8%) and $I_{H3} = 1.9$ (SD = 0.5).

Separation

Measurements performed during the first year of separation testing showed that the best values of indicator I_{S1} were obtained using 2.5 and 2.7 Hz oscillating frequencies and 8 mm and 6/8 mm rods' distances in the sieve sets, respectively. As shown in Fig. 5, results for indicator I_{S1} were 91.8% (SD = 2.1%) for 2.5 Hz and 8 mm combination and 91.2% (SD = 2.8%) for 2.7 Hz and 6/8 mm combination. The admixtures (leaves and stalks) remaining above the sieves were 49% (SD = 7.6%) and 26.5% (SD = 5.5%), respectively.

Fig. 5 also shows the indicator I_{S2}, which represents the ratio of the mass of inflorescences with stem length up to 2 cm and the mass of inflorescences with stem length over 2 cm, calculated for the 2 cm stem length,

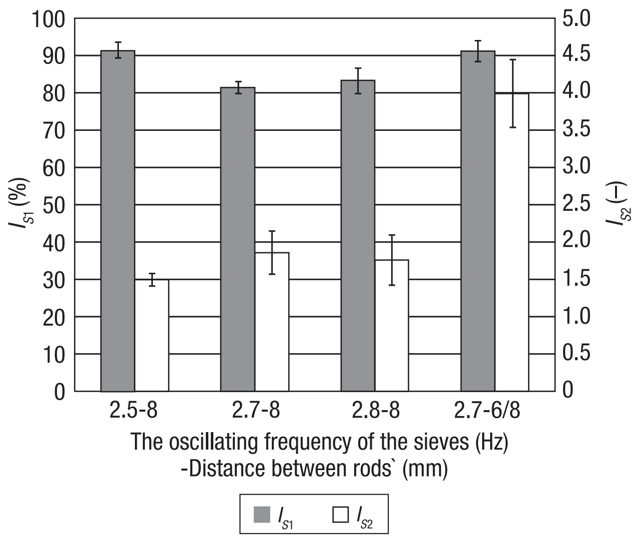

Figure 5. Indicators of separation efficiency I_{S1} (%) and I_{S2} (unitless) for different values of oscillating frequency and distance between the rods, in the first season of testing the separation. Values in the histograms are significant at the $p \leq 0.05$ probability level. Bars on the histograms represent standard deviation.

separated over the sieves. The highest value of $I_{S2} = 3.99$ (SD = 0.43) was achieved with 2.7 Hz oscillating frequency and 6/8 mm rod distance combination. The lowest result of $I_{S2} = 1.49$ (SD = 0.06) was obtained using the 2.5 Hz oscillating frequency and 8 mm rod distance.

The plant mass which fell through the sieves at 2.7 Hz oscillating frequency and with the 6/8 mm rod distance, contained 3.0% (SD = 0.1%) of inflorescences, which represents 8.8% (SD = 0.5%) of the total mass of inflorescences present in the processed material.

The investigation results of the first year indicated that the best separation effects were achieved using the 2.7 Hz oscillating frequency of the crankshaft and the 6/8 mm distance between the rods in the sieves. Also, it was concluded that the plant mass which passed over the sieves should be additionally sieved two more times. During the second season, five measurements were performed with these parameters. The obtained average value of I_{S1} was 92.4% (SD = 2.9%) whereas the average result for I_{S2} was 5.2 (SD = 1.0).

The investigation showed that the separation of inflorescences from the rest of the harvested mass can be conducted before drying, which can also contribute to a reduction of the energy input. Shortening the stems' length to 2 cm remains a problem that should be solved. The solution could be a redesigned device, already used for the same purpose in chamomile inflorescence processing (Martinov & Oluski, 1998).

Based on the presented long-term investigations of possibilities for mechanized harvest and separation of marigold inflorescences, it can be concluded that the mechanized harvest of marigold inflorescences using virtual rotating comb type harvester with wide tines distance is viable and efficient. The highest percentage of the total harvested mass of inflorescences, 84-97%, related to total inflorescences yield is achieved when the coefficient of relative penetration of the harvesting device into the width of inflorescences band, is set to $R = 1.3$.

As a consequence of buds' damages and elimination, the next harvesting recurrence can be performed after 15 to 20 days, depending on weather conditions. The total inflorescences yield during a harvest season decreases or stagnates, as a direct result of buds damages.

Post-harvest inflorescences separation, before drying, can be realized by a simple device based on combine harvester walker, through which three passes are needed in order to achieve good separation. The mass separated above sieves is then 92% of the total harvested inflorescences. The quantity of inflorescences with stem length up to 2 cm is on average five times higher than those of stems longer than 2 cm.

Shortening the inflorescences stems longer than 2 cm to the technologically acceptable length of up to 2 cm requires further investigations.

Future investigations should be directed at assessing the economic viability of mechanized harvesting in contrast to manual picking, where yields decrease and the processing costs deserve special attention.

When the performance of the tested harvester is compared with the published results of mechanized harvesting of chamomile inflorescences, no considerable differences in the overall working effects can be identified, thus proving its applicability and usability. Similar results of marigold harvest might also be achieved by other inflorescence harvesting machines. The application of the tested machines, the virtual rotating comb type chamomile harvester and the customized separator, represent a low-cost solution that may contribute to much better economic indicators.

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