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Constituent Elements, pH and Electrical Conductivity Values of Feedstock, Ash and Slow Pyrolysis Derived Biochar of Date Palm Wastes

Sastavni elementi, pH vrijednost i električna provodnost sirovine, pepela i biougljena dobivenoga sporom pirolizom od otpadaka palme datulje

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ABSTRACT • *Date palm wastes (rachis and dried stems) are feasible biomass to be treated and used for soil improvement and restoration purposes. Identified properties of processed forms of such biomass are required for their deliberated applications in compensating for any types of soil deficiencies. For this task constituent elements, pH and electrical conductivity (EC) values of fiber bundles, ash and slow pyrolysis derived biochar of these wastes were determined. Test materials were from two palm groves, differentiated by governing ecological conditions, named tropical and dry zones, to study climate impacts on the same palm species. Experimental data have shown that discrepancies in the percentages of C, H, N and S in three types of waste from the humid zone are not drastic. Their ashes are alkaline, but feedstock and biochar are acidic. EC values are high in ashes, but low in feedstock and biochar. C/N ratios do not change considerably. The same results were also observed for dry zone wastes, except their C/N ratio which is drastically higher. Percentages of measured properties of wastes from sampled groves were also compared for climate impacts. In terms of properties, differences between three forms of waste from two groves require to be considered when used for soil improvement purposes.*

KEYWORDS: *palm waste; constituent element; biochar; ash; fiber bundles; pyrolysis*

SAŽETAK • *Otpatke od palme datulje (lisne osi i osušene stabljike) moguće je iskoristiti za biomasu koja se može obrađivati i dalje upotrebljavati za poboljšanje i obnovu tla. Za promišljenu primjenu u nadoknadi bilo kakvog*

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nedostatka tla potrebno je poznavati svojstva prerađenih oblika te biomase. Stoga su u ovom istraživanju određeni sastavni elementi, pH vrijednost i električna provodnost (EC) snopova vlakana, pepela i biougljena dobivenoga sporom pirolizom otpadaka palme datulje. Kako bi se proučili klimatski utjecaji na tu vrstu palme, odabrani su uzorci iz dvaju nasada palmi koje su rasle u različitim ekološkim uvjetima nazvanima vlažna i suha zona. Eksperimentalni podatci pokazali su da odstupanja u postotcima elemenata C, H, N i S u sirovim vlaknima, pepelu i biougljenu palminih otpadaka iz vlažne zone nisu značajna. Pepeo je alkalan, ali su sirova vlakna i biougljen kiseli. EC vrijednosti su u pepelu visoke, ali su u sirovim vlaknima i biougljenu niske. C/N omjeri značajno se ne razlikuju. Jednaki rezultati dobiveni su i za otpadak od palmi iz suhe zone, osim što su C/N omjeri znatno viši. Izmjerena svojstva palminih otpadaka uspoređena su i s obzirom na klimatske utjecaje na nasad palmi, odnosno uspoređeni su uzorci iz vlažne i suhe zone. Pri uporabi palmine biomase za poboljšanje tla moraju se uzeti u obzir razlike između svojstava sirovih vlakana, pepela i biougljena iz dvaju nasada palmi.

KLJUČNE RIJEČI: *otpadci od palmi; sastavni element; biougljen; pepeo; snopovi vlakana; piroliza*

1 INTRODUCTION
1. UVOD

Date palm *(Phoenix dactilyfera)* wastes include rachis and dried stems. Rachis is more abundant since date farmers prune about 15 dried rachises from each fruit producing palm tree every year. Weight of trimmed rachis (fronds) comprises million metric tons annually. Dried stems are also rather plentiful wastes in date palm groves (palm trees stands). There are no official referable records of palm wastes (from both fruit bearing and nonfruit bearing palm stands), except a local date (Ahmadi *et al*., 2015). Proper utilization of these biomass has no history so far, although they contain valuable chemical substances (Ebrahimi *et al*., 2021; Ebrahimi *et al*., 2022). Some basic compositions of these wastes were studied in laboratory scale (see Tables 3, 4, 13 in Jonoobi *et al*., 2019). Some unpublished results of case studies on date palm wastes were reviewed as well.

Their use as raw material in producing fiber-based products was proposed, since these wastes are fibrous materials (Prasad and Power, 1991). Such concept of utilizing these residuals requires continuous removal of these wastes from palm groves as they would damage the groves environmentally, because end products are unreturnable to palm groves as fertilizer or any kind of soil amendment agent. Therefore, in the long run, the soil of groves would not be nutritious for the trees.

The right procedure for managing these residuals (Brewer *et al*., 2011) is to convert them into useful additives for soil amendment and restoration. This concept is compatible with environmental issues as well (Kamperidou *et al.,* 2021).

During recent decade, the concept of conversion of crop biomass through thermochemical process (pyrolysis) into solid (biochar) and liquid (vinegar) substances as returnable additives to soils under cultivations has been developed (Kloss *et al*., 2012).

Application of this kind of treatment on biomass residual has been extended to date palm wastes conversion as well. However, quite a few instructive research reports dealing with properties of biochar (Ronsse *et al*., 2013; Jouiad *et al*., 2015; Bensidhom *et al*., 2018; Usman *et al*., 2015), its uses as green sorbents of organic and inorganic pollutants (Usman *et al*., 2016; Al-Wabel *et al*., 2019), improving soil fertility, upgrading and remediation degraded soils (Al-Wabel *et al*., 2019; Beesley *et al*., 2011) and climate change mitigation (Hussain *et al*., 2014) have been published.

The above studies have clearly shown the positive functions of pyrolysis derived biochars. As mentioned earlier, the pyrolysis process is not harmful to the environment and pyroligneous gases from biomass pyrolysis can mostly be condensed by a properly designed system.

Another known pyrolytic product is bio-oil or vinegar, also called bio-fuel (Woolf *et al*., 2010), which results from condensing volatiles emitted from pyrolysis reactors with chemical content depending on temperature used in pyrolysis processes.

The objectives of this investigation were to characterize feedstock, ash and biochar samples from date palm wastes for their constituent elements, pH and EC (Index of soluble salt in soil solution) values, comparing rachis (fronds) and stem from each sampled grove and from groves in tropical and dry zones for finding ecological impact on the above variables. These objectives were designed to evaluate the potentiality of three forms of palm wastes mainly for their farming purposes. Results of this work will be useful for making proper use of such plentiful biomass (Prasad and Power, 1991; Power and Prasad, 1997).

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

For this study, date palm wastes (dry rachis and stems) samples were collected from palm groves in Lamerd (southern territory of Fars province, in hot and humid climate zone) and Kerman (southeast province of Iran, a hot and dry climate zone). The purpose of collecting test materials from date palm groves in two different climate zones was to find discrepancies in wastes elemental contents due to ecological impacts, if any; however, the palm species was the same.

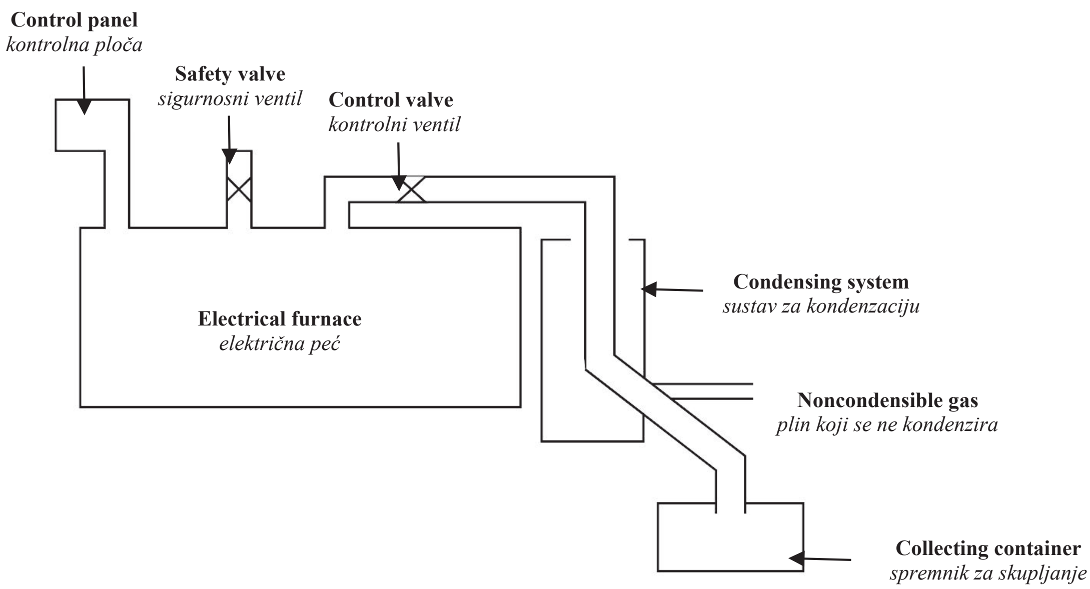

Figure 1 Pyrolysis apparatus
Slika 1. Oprema za pirolizu

Test materials were air dried to about 12, 7.5, 5 % moisture content, then chipped into particles, measuring 10-15 mm in length, less than several millimeters in thickness. Samples of rachis and stem (types of waste) were separately divided into three randomized sets. A set of each type of waste was mechanically defibrated for receiving fiber bundles (feedstock specimens). A slow pyrolysis process was conducted on one set in a laboratory scale electrical furnace (designed and shop fabricated, Figure 1). The third set of samples of each type of waste was burnt down to ash in an open fire. From each set of samples after the application of designated treatment, random specimens were drawn for C, H, N, S analysis.

2.1 C, H, N, S analysis
2.1. Analiza elemenata C, H, N i S

As mentioned above, randomly chosen specimens of feedstock (fiber bundles), ash and biochar (out of rachis & stem wastes of date palm) were analyzed (by Flash EA 1112 Series, Thermos Finnegan, Mass. USA) for their constituent elements, namely C, H, N and S. Table 1 presents accumulated data (mean and coefficient of variation) on percentages of elemental

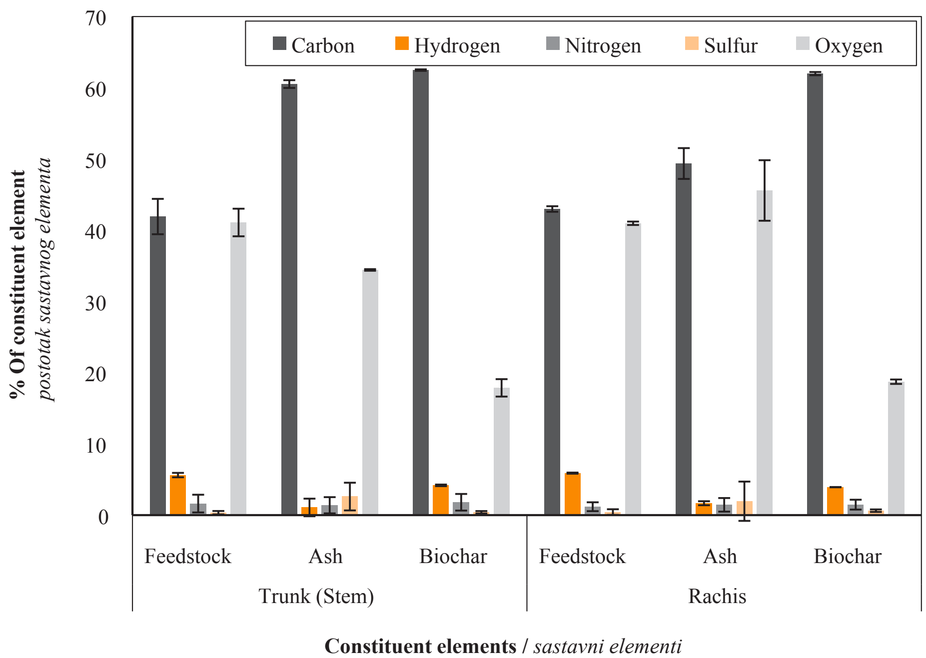

Figure 2 Mean percentages and corresponding error bars of C, H, N, S and O in feedstock, ash and biochar of date palm wastes from groves in humid climate zone (Lamerd)
Slika 2. Srednja vrijednost postotaka i odgovarajući stupci pogrešaka za elemente C, H, N, S i O u sirovim vlaknima, pepelu i biougljenu od otpadaka palme datulje iz nasada u zoni vlažne klime (Lamerd)

Table 1 Average and coefficient of variation of percentages of constituent elements, pH, EC and calculated molar ratios of feedstock, ash and biochar from date palm wastes (stem and rachis) from grove in humid climate zone (Lamerd)
Tablica 1. Srednja vrijednost i koeficijent varijacije postotaka sastavnih elemenata, pH, EC i izračunanih molarnih omjera sirovih vlakana, pepela i biougljena od otpadaka palme datulje (stabljike i lisne osi) iz nasada u zoni vlažne klime (Lamerd)

Variables *Varijable*	**Trunk (Stem)** / *Deblo*						**Rachis (Fronds)** / *Lisne osi (lišće)*					
	Feedstock* *Sirovina**		**Ash** *Pepeo*		**Biochar** *Biougljen*		**Feedstock** *Sirovina*		**Ash** *Pepeo*		**Biochar** *Biougljen*	
	Ave.	CV%**	Ave.	CV%	Ave.	CV%	Ave.	CV%	Ave.	CV%	Ave.	CV%
MC, % *sadržaj vode*, %	12.60	8.45					11.65	14.05				
Biochar, % *biougljen*, %	49.72						51.61					
Bio-oil, % *bioulje*, %	31.61						29.64					
Volatiles, *hlapljivi spojevi*, %	18.67						18.75					
Ash content, % *sadržaj pepela*, %	8.55				13.27		8.55				13.27	
Content of element, % *Sadržaj elemenata*, %												
C	41.91	5.92	60.51	0.89	62.47	0.19	42.90	0.91	49.36	4.37	61.98	0.36
H	5.62	5.53	1.07	115	4.18	0.11	5.89	1.35	1.70	16.8	3.93	0.56
N	1.62	76.82	1.38	82.31	1.80	64.60	1.18	52.50	1.45	65.50	1.47	47
S	0.34	70.59	2.61	74.33	0.40	42.5	0.43	91.85	1.95	141.40	0.63	34.92
O	41.10	4.71	34.42	0.33	17.86	6.85	40.97	0.59	45.57	9.32	18.73	1.70
pH***	4.10		10.30		6.30		4.23		11.23		6.11	
EC***	4.23 ds/m		15.42 ds/m		3.51 ds/m		4.20 ds/m		15 ds/m		3.50 ds/m	
Molar ratio												
O/C	0.98		0.56		0.28		0.95		0.92		0.30	
H/C	0.13		0.02		0.07		0.14		0.03		0.06	
(O+N/C)	1.02		0.56		0.31		0.98		0.95		0.32	
O+N+S/C)	1.03		0.63		0.32		1		1		0.33	
C/N	35.88	72.57	66.25	82.72	43.78	54.50	42.40	53.62	44.33	69.45	47.48	47.46

Due to seasonal dependency of *MC*, feedstock density is variable as well. / *Zbog sezonske ovisnosti sadržaja vode gustoća sirovine također je promjenjiva*.
**CV was adopted rather than standard deviation. / ***CV je odabran umjesto standardne devijacije.*
***In the extract for measuring pH and EC values, ratio of solid substance to water was maintained 1:2.5. / ****U ekstraktu za mjerenje pH i EC omjer suhe tvari i vode bio je 1:2,5.*

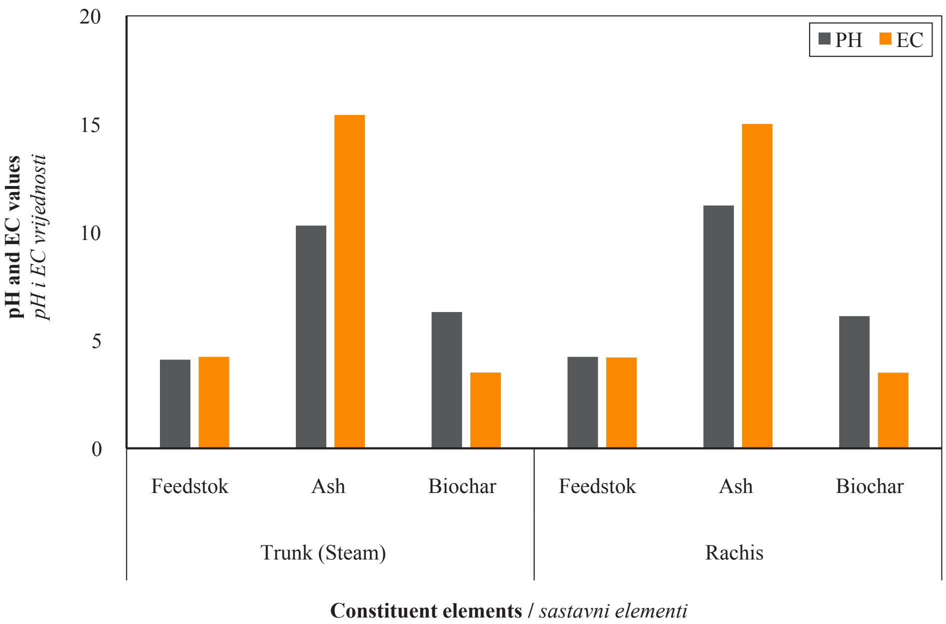

Figure 3 pH and EC values of feedstock, ash and biochar of date palm wastes from groves in humid zone (Lamerd)
Slika 3. pH i EC vrijednosti sirovih vlakana, pepela i biougljena od otpadaka palme datulje iz nasada u zoni vlažne klime (Lamerd)

Table 2 Average and coefficient of variation of percentages of constituent elements of feedstock, ash and biochar from date palm wastes (stem and rachis) from groves in dry climate zone (Kerman)
Tablica 2. Srednja vrijednost i koeficijent varijacije postotaka sastavnih elemenata, pH, EC i izračunanih molarnih omjera sirovih vlakana, pepela i biougljena od otpadaka palme datulje (stabljike i lisne osi) iz nasada u zoni suhe klime (Kerman)

Variables *Varijable*	**Trunk (Stem)** / *Deblo*						**Rachis (Fronds)** / *Lisne osi (lišće)*					
	Feedstock *Sirovina*		**Ash** *Pepeo*		**Biochar** *Biougljen*		**Feedstock** *Sirovina*		**Ash** *Pepeo*		**Biochar** *Biougljen*	
	Ave.	CV%	Ave.	CV%	Ave.	CV%	Ave.	CV%	Ave.	CV%	Ave.	CV%
MC, % *sadržaj vode, %*	7.50	8.21					4.89	6.34				
Biochar, % *biougljen, %*	57.15						51.70					
Bio-oil, % *bioulje, %*	32.21						34.90					
Volatiles, % *hlapljivi spojevi, %*	10.63						13.40					
Ash content, % *sadržaj pepela, %*	8.50				12.5		8.50				13.30	
Content of element, % *Sadržaj elemenata, %*												
C	40.78	6.30	15.53	105	58.60	5.37	40.78	4.60	32.89	31.53	59	9.34
H	5.45	15	1.13	0.66	2.25	102	4.52	2.45	1.46	5.82	4	0.25
N	0.27	50	0.45	142	0.63	117	0.55	114	0.40	52.50	1	3.60
S	0.47	59.60	2.76	64	2.29	77	0.51	16.70	1.35	78.50	0.61	4.64
O	44.53	9.10	80.59	19.7	23.74	18.65	44.12	2.32	63.40	14.53	22	25.20
pH	4.20		10.25		6.30		4.60		11.20		6.11	
EC	4.91 ds/m		4.20 ds/m		10.50 ds/m		15.35 ds/m		10 ds/m		11.70 ds/m	
Molar ratio												
O/C	1.09		5.18		0.41		1.08		1.92		0.37	
H/C	0.13		0.07		0.04		0.11		0.18		0.68	
(O+N/C)	1.10		5.22		0.42		1.10		1.94		0.39	
O+N+S/C)	1.11		5.40		0.45		1.11		1.98		0.40	
C/N	39.45	141	15	142	308	117	211	115	103.70	77.80	61.2	0.16

contents in feedstock, ash and biochar of stem and rachis from humid climate zone (Lamerd) date palm grove. In Table 1 molar rations were calculated through determination of the percentages of oxygen by Eq. 1 (Al-Wabel *et al.*, 2019):

$$Percentage\ of\ oxygen = 100 - (C + H + N + S + ash\%) \quad (1)$$

Figure 2 graphically shows the mean percentages, coefficient of variation and corresponding error bar of each constituent element of feedstock, ash and biochar out of sampled stem and rachis from groves in humid zone (Lamerd).

The pH and EC values of feedstock, ash and biochar of palm residuals from humid climate zone were measured as well.

Table 1 also contains data of these variables. Figure 3 presents these data graphically.

The same procedure was used for presenting data of sampled stem and rachis of date palm wastes from palm groves in Kerman territory, the dry climate zone. Table 2 presents relevant experimental data of these groves. Figure 4 is the graphical presentation of data in Table 2. pH and electrical EC values of related samples are shown graphically in Figure 5.

Volatiles in each Table (1, 2) are the remainder of feedstock weight minus sum of the produced bio-oil and biochar weights. Determination of volatiles by adopting either ASTM4 D1762-8 specification or applying A proposed modified method for analysis of biochar biochar (Skjemstad *et al.,* 2002) was not possible, due to the lack of the proper equipment.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

As mentioned in the introduction, plentiful date palm residual is not utilized nor used in a beneficial manner. Mostly these wastes are scattered left in dry slashes form over palm groves floor. They are partially burnt, risking the expansion of flames and producing smoke that pollutes the environment. The ashes resulting from the waste burning process are not distributed evenly across the groves. Surface run-offs coming from precipitation and irrigation may contribute to the distribution of these ashes to some extent. Dealing with these valuable wastes in such a primitive manner is not productive. These wastes deserve to be utilized methodically based on scientific and technological achievements in order to develop products with higher added value.

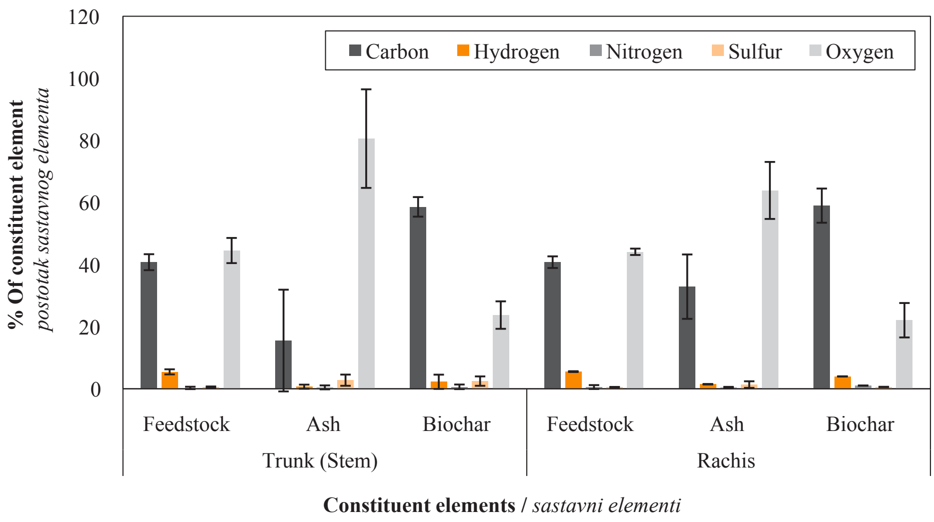

Figure 4 Mean percentages and corresponding error bars of C, H, N, S and O in feedstock, ash and biochar of date palm wastes from groves in dry climate zone (Kerman)
Slika 4. Srednja vrijednost postotaka i odgovarajući stupci pogrešaka za elemente C, H, N, S i O u sirovim vlaknima, pepelu i biougljenu od otpadaka palme datulje iz nasada u zoni suhe klime (Kerman)

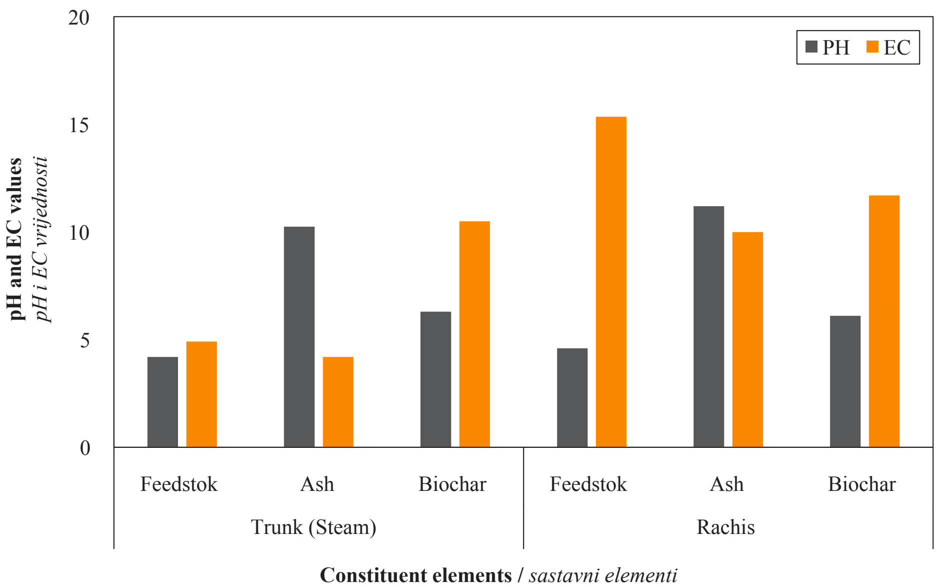

Figure 5 pH and EC values of feedstock, ash and biochar of date palm wastes from groves in dry zone (Kerman)
Slika 5. pH i EC vrijednosti sirovih vlakana, pepela i biougljena od otpadaka palme datulje iz nasada u zoni suhe klime (Kerman)

3.1 Applicable forms of date palm wastes for soil amendment
3.1. Primjenjivi oblici otpadaka palme datulje za poboljšanje tla

3.1.1 Fiber bundles (feedstock)
3.1.1. Snopovi vlakana (sirovina)

The most abundant date palm waste comes from rachis (fronds), since twice a year rachis trimming takes place. Palm trees last a long time, mostly more than a century, however their dried slashes are found rather frequently throughout the old palm groves. Palm tree stem (trunk) is mostly the remainder of pruned rachis in its circumference and therefore it should contain elements that are present in rachis. Thus, this type of waste should not be ignored.

The addition of feedstock fiber bundles to soil either from stem or rachis is not recommended because it takes a longer time to decay and decompose completely and it has been also recognized that organic soil improvement with organic decomposable substrates can contribute to global warming and greenhouse gases (Al-Wabel *et al.*, 2019). However, the basic elements (C, H, N, S, O) as well as C/N ratio, pH and EC values in fiber bundles (feedstock) are comparable to those in ash and biochar. Therefore, it may function better in some areas of farming activities, like in fish and shrimp farming ponds.

Preparing ash from date palm waste seems the simplest way of converting these residuals into soil additive, and soil exports generally agree with such additive as a soil amendment agent, but it cannot be as good as biochar.

3.1.2 Biochar
3.1.2. Biougljen

Biochar is the preferred type of converted biomass through thermo-chemical process, due to its desired properties when compared with any other soil additives. Biochar was evaluated as green sorbent (Al-Wabel *et al.,* 2019) for removing organic and inorganic pollutants in aqueous solutions. All three kinds of date palm wastes are functional additives to the soil.

3.2 Comparisons of three types of date palm wastes from stem and rachis in each sampled grove
3.2. Usporedbe triju vrsta otpadaka palme datulje sa stabljike i lisnih osi u svakoj uzorkovanoj brazdi

3.2.1 Wastes from palm grove in humid climate zone
3.2.1. Otpadci iz palmine brazde u zoni vlažne klime

Fiber bundles, ash and biochar of stem and rachis were compared for their elemental contents in Table 3. This Table shows as follows:

In feedstock:

Carbon - carbon in stem feedstock is less than that of rachis by 2.52 %.

Hydrogen - rachis has more hydrogen (4.80 %) than stem.

Nitrogen - nitrogen is more pronounced in stem feedstock than in rachis by 27 %, a noticeable difference.

Sulfur - stem fiber bundles contain more sulfur than fiber bundles of rachis by 26 %, a rather significant difference.

Oxygen - the amount of oxygen is 10.87 % higher in rachis than in stem.

C/N ratio - this ratio in fiber bundles of rachis is greater than that of stem by 18 %, a slight discrepancy.

pH values of the feedstock of both stem and rachis are acidic, fiber bundles of rachis are less acidic by 3.17 %, which is a little discrepancy.

EC values - fiber bundles (feedstock) of stem and rachis have the same EC values.

In ash:

Carbon - the percentage of carbon in stem ash is 41 % greater than that of rachis.

Hydrogen - hydrogen content in stem ash is 58 % higher than in rachis ash.

Nitrogen - the percentage of nitrogen in stem ash is only 5.80 % higher than in rachis ash.

Sulfur - this element is higher by 34 % in stem ash than in rachis ash.

Oxygen - rachis ash is richer in oxygen than stem ash by 32 %.

pH values - ashes of both segments (stem and rachis) are alkaline. Alkalinity of ash made from rachis is slightly higher, by 9 %.

EC values - this variable has almost the same value in ashes from stem and rachis.

C/N ratio - this ratio in stem ash is 49% greater than that of rachis.

In biochar:

Carbon - the percentages of carbon in biochar of stem and rachis is almost the same, an ignorable discrepancy of 0.8 % is calculated.

Hydrogen - biochar of stem contains 6.36 % more hydrogen than rachis biochar.

Nitrogen - this element in stem biochar is 22 % greater than in rachis biochar, this being considered a moderate difference.

Sulfur - rachis biochar is more sulfur-rich, by 57 %, comparing with that of stem, a noticeable difference.

Oxygen - calculated amount of oxygen in rachis biochar is 4.87 % greater than in stem biochar.

pH values, biochar of both segments stem and rachis of palm waste are acidic, almost equally, with only a 3 % difference.

EC values - this variable has equal values in biochar of both segments of palm wastes.

C/N ratio - in this ratio, rachis biochar is 8.57 % richer than stem biochar.

3.2.2 Wastes from palm grove in dry climate zone
3.2.2. Otpadci od palmi iz nasada u zoni suhe klime

Fiber bundles, ash and biochar of stem and rachis are compared in terms of percentages of constituent elements in Table 4. This table shows as follows:

In feedstock:

Carbon - rachis feedstock has equal amount of carbon with that in stem.

Hydrogen - in stem feedstock, hydrogen is 21 % higher compared to that of rachis.

Nitrogen - in rachis feedstock, nitrogen is 2 times richer than in stem feedstock.

Sulfur - in rachis feedstock, the percentage of sulfur is 8.5 % higher.

Oxygen - calculated value of oxygen is equal to that in stem and rachis feedstock.

pH values - rachis feedstock is 9.5 % less acidic than that of stem.

EC values - this parameter is 3 times higher in rachis feedstock than in stem.

C/N ratio - this ratio in rachis feedstock is 5.35 times greater than in stem feedstock.

In ash:

Carbon - rachis ash is 2.11 times richer in carbon with respect to stem ash.

Hydrogen - this parameter in rachis ash is 29 % higher than that of ash generated from stem.

Nitrogen - the amount of this element in stem ash is greater than in rachis ash by 12.5 %.

Table 3 Comparison of percentage of constituent elements (C, H, N, S, O), pH, EC and C/N ratio in types of waste (stem and rachis) – Lamerd date palm grove (humid climate zone)
Tablica 3. Usporedba postotaka sastavnih elemenata (C, H, N, S, O), pH, EC i C/N omjera u vrstama otpadaka (deblo i lisne osi) – nasad datulje Lamerd (zona vlažne klime)

Segment sampled *Uzorkovani segment*		**C, %**		**H, %**		**N, %**		**S, %**		**O, %**		**pH**		**EC, ds/m**		**C/N**	
		Value *Vrijed-nost*	% diff. or ratio*	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio
Feedstock *Sirovina*	Stem / *deblo*	41.10	2.52	5.62	4.80	1.62	1.37	2.34	1.26	41.10	0.32	4.10	3.17	4.23	0.71	35.88	1.18
	Rachis / *lisne osi*	42.97		5.89		1.18		0.43		40.97		4.23		4.20		42.40	
Ash *Pepeo*	Stem / *deblo*	60.51	1.41	1.07	1.58	1.38	5.80	2.61	1.34	34.42	1.32	10.30	9	15.42	2.80	66.25	1.49
	Rachis / *lisne osi*	42.97		1.70		1.46		1.95		45.57		11.23		15		44.33	
Biochar *Biougljen*	Stem / *deblo*	62.47	0.80	4.18	6.36	1.80	1.22	0.40	1.57	17.86	4.87	6.30	3	3.51	0.28	43.73	8.57
	Rachis / *lisne osi*	61.98		2.93		1.47		0.63		18.73		6.11		3.50		47.48	

*% diff. were calculated with respect to lower values, and ratios were determined by higher values to lower ones
**Postotne su razlike izračunane s obzirom na niže vrijednosti, a omjeri su određeni odnosom viših vrijednosti prema nižima.*

Table 4 Comparison of percentage of constituent elements (C, H, N, S, O), pH, EC values and C/N ratio in types of waste (stem & rachis) – Kerman date palm grove (dry climate zone)
Tablica 4. Usporedba postotaka sastavnih elemenata (C, H, N, S, O), pH, EC i C/N omjera u vrstama otpadaka (deblo i lisne osi) – nasad palme datulje Kerman (zona suhe klime)

Segment sampled *Uzorkovani segment*		**C, %**		**H, %**		**N, %**		**S, %**		**O, %**		**pH**		**EC, ds/m**		**C/N**	
		Value *Vrijed-nost*	% diff. or ratio*	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio	Value *Vrijed-nost*	% diff. or ratio
Feedstock *Sirovina*	Stem / *deblo*	40.78	1	5.45	1.21	0.27	2 times	0.47	8.50	44.53	0.92	4.20	9.50	4.91	3 times	39.45	5.35
	Rachis / *lisne osi*	40.78		4.52		0.55		0.51		44.12		4.60		15.35		211	
Ash *Pepeo*	Stem / *deblo*	15.53	2.11	1.13	1.29	0.45	12.5	2.76	2.04	80.59	27	10.25	9.26	4.20	2.40 Times	15	6.91
	Rachis / *lisne osi*	32.89		1.46		0.40		1.25		63.40		11.20		10		103.70	
Biochar *Biougljen*	Stem / *deblo*	58.60	0.70	2.25	1.78 times	0.63	1.58	2.29	3.75 times	23.74	7.90	6.30	1.47	10.50	1.11	308	5 times
	Rachis / *lisne osi*	59		4		1		0.61		22		6.11		11.7		61.2	

*% diff. were calculated with respect to lower values, and ratios were determined by higher values to lower ones
**Postotne su razlike izračunane s obzirom na niže vrijednosti, a omjeri su određeni odnosom viših vrijednosti prema nižima.*

Table 5 Comparison of date palm wastes from groves in humid and dry climate zones, in terms of constituent elements (C, H, N, S, O), pH, EC values, and C/N ratios
Tablica 5. Usporedba otpadaka palme datulje iz nasada u vlažnoj i suhoj klimatskoj zoni s obzirom na sastavne elemente (C, H, N, S, O), pH, EC vrijednosti i omjer C/N

Segment sampled *Uzorkovani segment* Humid zone *Vlažna zona*		C, %			H, %			N, %			S, %							pH			EC, ms			C/N	
		Dry zone *Suha zona*	% diff. or ratio* *Postotna razlika*	Humid zone	Dry zone	% diff. or ratio*	Humid zone	Dry zone	% diff. or ratio*	Humid zone	Dry zone	% diff. or ratio*	Humid zone		Dry zone	% diff. or ratio*	Humid zone	Dry zone	% diff. or ratio*	Humid zone	Dry zone	% diff. or ratio*	Humid zone	Dry zone	% diff. or ratio*
Feedstock / *Sirovina* Ash / *Pepeo*	Stem *deblo* Rachis *lisne osi*	41.91	40.78	2.80	5.62	5.45	3.11	1.62	0.27	6.00 times	0.34	0.27	25.90	41.10	44.53 8.34			4.10	4.20 2.43		4.23	4.91 16		35.88	39.45 10
	Stem *deblo* Rachis *lisne osi*	-42.91	40.78	5.20	5.89	2.45	2.40 times	1.18	0.40	2.95 times	0.43	0.45	4.65	40.97	44.12 7.68			4.23	4.60 8.74		4.20	15.36 3.70 times		42.40	211 5 times
Biochar / *Biougljen* Feedstock / *Sirovina*	Stem *deblo*	60.51	15.53	3.90 times	1.07	1.13	5.60	1.38	0.45	3.10 times	2.61	2.76	5.75	34.42	80.59 2.34 times			1030	10.25 0.48		15.42	4.20 3.67 times		66.25	15 4.42 times
	Stem *deblo* Rachis *lisne osi*	49.36	32.89	1.50 times	1.35	1.45	7.40	1.45	0.55	2.63 times	1.96	1.35	44	45.57	63.40 39			11.23	11.20 0.27		15	10 1.50 times		44.33	163.70 2.34 times
Ash / *Pepeo*	Stem *deblo* Rachis *lisne osi*	62.47	58.60	6.60	4.12	2.25	1.83	1.80	0.63	2.85 times	0.40	2.29	5.72 times	17.86	23.74 32.93			6.30	6.30 1		3.51	10.50 3 times		43.73	308 7 times
	Stem *deblo*	61.98	59	5.10	3.93	4	1.78	1.47	1	47	0.63	0.61	3.27	18.73	22 17.45			6.11	6.11 1		3.50	11.7 3.34 times		47.48	61.2 28.90

% diff. were calculated with respect to lower values, and ratios were determined by higher values to lower ones / *Postotne su razlike izračunane s obzirom na niže vrijednosti, a omjeri su određeni odnosom viših vrijednosti prema nižima.*

Sulfur - stem ash is twice as rich in sulfur as rachis ash.

Oxygen - calculated amount of oxygen in stem ash is 27 % higher.

pH values - rachis ash is more alkaline by 9.26 % than stem ash.

EC values - this parameter in rachis ash is 2.4 times greater than in stem ash.

C/N ratio - this ratio in rachis ash is 6.91 times higher than that of stem.

In biochar:

Carbon - the percentage of carbon in rachis biochar is 0.70 % higher than that of stem biochar.

Hydrogen - rachis biochar is 78 % richer than biochar from stem.

Nitrogen - the percentage of nitrogen in rachis biochar is 58 % higher than that in stem biochar.

Sulfur - this element in stem biochar is 3.75 times greater than in rachis biochar.

Oxygen - calculated amount of oxygen in stem biochar is 7.90 % higher.

pH values - the difference between biochar of stem and rachis in pH is small, 1.47 %.

C/N ratio - this ratio in stem biochar is 5 times higher than that of rachis biochar.

3.2.3 Comparisons of climatological impacts on date palm wastes through characterized parameters

3.2.3. Usporedbe klimatoloških utjecaja na otpatke od palme datulje uz pomoć karakterističnih parametara

Samples of date palm wastes were collected from two different palm groves in terms of governing climatical conditions (Lamerd, hot and humid zone, Kerman, hot and dry zone), to evaluate discrepancies collected from three types of waste (feedstock, ash and biochar) are compared in Table 5.

Feedstock:

Carbon - stem feedstock from the humid zone contains more carbon, by 2.80 %. Carbon content of rachis feedstock from the same zone is slightly higher, by 5.20 %. Therefore, in terms of carbon content, no drastic differences have been observed in stem and rachis feedstock from either zone.

Hydrogen - hydrogen percentage in stem feedstock from the humid zone differs by 3.11 % from that of the dry zone. In rachis feedstock from the humid zone, the percentage of hydrogen is 2.40 times greater than that of the dry zone. It can be concluded that percentages of hydrogen in stem and rachis feedstock from either zone differ by 3.11 % to 2.40 times, respectively, which may not be considered negligible.

Nitrogen - nitrogen percentage is 6 times greater in stem feedstock in the humid zone. Therefore, the stem feedstock from the humid zone might be considered rather nitrogen-rich. In the rachis feedstock from the humid zone, the percentage of nitrogen is 2.95 times higher than that of the dry zone.

Sulfur - in the stem feedstock from the humid zone, the percentage of sulfur is 25.90 % greater than that of the dry zone. In rachis feedstock from the dry zone, sulfur content is 4.65 % higher than that of the humid zone.

Oxygen - the percentage of oxygen in feedstock from the dry zone is 8.34 % higher than that of the humid zone. Rachis feedstock from the dry zone contains more oxygen by 7.68 %.

pH value - stem feedstock from both zones has close acidic pH values (4.10, 4.20) and that of rachis has slightly less acidic pH, with an insignificant difference (4.23, 4.60).

EC values - in the stem feedstock from both sampled zones, EC values are close (4.23 ms and 4.91 ms) with a negligible difference. EC value in the rachis feedstock from the dry zone is 3.7 times greater than that of the humid zone. This might be important to consider when selecting feedstock (fiber bundles) of rachis from the dry zone as a soil additive.

C/N ratio - in stem feedstock from the dry zone, C/N ratio is 10 % richer than that of stem feedstock from the humid zone. The C/N ratio in rachis feedstock from the dry zone is 5 times greater than that of rachis feedstock from the humid zone.

Ash:

Carbon - Carbon content in the stem ash from the humid zone is 3.90 times higher than that of the dry zone. This difference is considerable.

In rachis ash from the humid zone carbon content is higher by 50 % (1.50 times). This is a relatively significant difference, and might be important, depending on cases of applications.

Hydrogen - the ash of the stem from the humid zone contains less hydrogen than corresponding ash from the dry zone by 5.60 %. The difference in hydrogen contents might be of interest in conjunction with areas of application.

The discrepancy in hydrogen content of rachis ash from the dry zone is 7.40 % higher compared with that of the humid zone.

Nitrogen - stem ash from the humid zone is 3.10 times higher than in stem ash from the dry zone. In rachis ash from the humid zone, nitrogen content is 2.63 times greater than nitrogen content in rachis ash from the dry zone.

Sulfur - the percentage of sulfur in the stem ash from the dry zone is 5.75 % higher than that in stem ash from the humid zone, but it is greater by 44 % in the rachis ash from the humid zone.

Oxygen - the amount of oxygen calculated in stem ash from the dry zone is 2.34 times higher than in stem ash from the humid zone. In rachis ash from the dry zone, oxygen is calculated to be 39 % higher than in rachis ash from the humid zone.

pH values - the stem ash from both zones had close pH values, 10.3 and 10.26, practically the same.

pH values in the rachis ash from both zones were close also, 11.23 and 11.20.

EC values - this parameter in stem ash from the humid zone is 3.67 times greater compared with that of ash from the dry zone. This drastic difference would be important considering cases of applications.

EC in rachis ash from the humid zone is greater in comparison with that of rachis ash from the dry zone by 50 %. This difference is noticeable as well.

C/N ratio - this ratio had a value of 66.25 % in the stem ash from the humid zone and 15 % in stem ash from the dry zone, the latter being 4.42 times smaller.

C/N ratio in the rachis ash from the dry zone is 2.34 times higher compared with its value in rachis ash from the humid zone.

Biochar:

Carbon - the percentage of carbon in stem biochar from the humid zone is 6.60 % higher than its percentage in stem biochar from the dry zone.

In rachis biochar from the humid zone, the percentage of carbon is 5.10 % greater if compared with that of the dry zone. This difference in carbon contents in rachis biochar can be considered modest.

Hydrogen - the percentage of hydrogen in stem biochar from the humid zone differs from that of the dry zone by 83 %, which is a great difference.

In the rachis biochar from the dry zone, the percentage of hydrogen is higher by 1.78 %, which is not significant.

Nitrogen - the percentage of nitrogen in stem biochar from the humid zone is 2.85 times higher compared with that of the stem biochar from the dry zone. This difference is high enough to be considered, depending on cases of applications.

Nitrogen content in rachis biochar from the humid zone is 47 % greater than that in rachis biochar from the dry zone, which is a relatively drastic difference and deserves to be considered with respect to areas of use.

Sulfur - in the stem biochar from the dry zone, the percentage of sulfur is 5.72 times larger, but in the rachis biochar from the humid zone, the percentage of sulfur is 3.27 % higher, a negligible difference.

Oxygen - calculated percentages of oxygen in stem biochar from the dry zone is 32.92 % greater, while in rachis biochar from the same zone, the percentage of oxygen is higher by 17.45 %.

pH values - the stem and rachis biochar from both climate zones are considered acidic. Rachis biochar is slightly less acidic.

EC values - the value of this parameter in stem biochar from the dry zone is 3 times larger than its value in stem biochar from the humid zone.

In rachis biochar from the dry zone, EC is 3.34 times higher than EC value in the rachis biochar from the humid zone.

C/N ratio - this ratio in the stem biochar from the dry zone is 7 times larger than its amount in the stem biochar from the humid zone, the difference being meaningful.

In the rachis biochar from the dry zone, C/N ratio is 28.90 % higher. Such difference in C/N ratio might be of importance considering areas of uses.

4 CONCLUSIONS
4. ZAKLJUČAK

Valuable Wastes

Based on the collected experimental data, wastes of rachis (fronds) and stems in date palm groves, especially rachis which are plentiful compared to stem slashes (trunk of palm tree), contain considerable amounts of constituent elements (C, H, N, S, O), carbon in particular. Among the necessary elements in the soil for the growth of agricultural crops, carbon (absorbable), hydrogen, nitrogen and sulfur are ranked 1st, 2nd, 4th and 9th, respectively (Aller *et al.,* 2017).

Returning crops residuals to the soil, improves its physical properties (Brewer *et al.,* 2011). This concept can be generalized for date palm wastes, since they contain useful organic substances that can restore degraded soils in palm groves.

Producing fiber bundles by mechanically defibrating date palm wastes might be considered a low-cost organic soil amendment agent. However, fiber decomposition process can be a source of gaseous emission from the soil, which will contribute to increasing greenhouse gases (Al-Wabel *et al.* 2019). Ash carbon is less desirable when compared with absorbable biochar. Biochar is a biologically more stable soil additive that changes the soil microbial community composition and enzyme activities (Prasad and Power, 1991).

C/N Ratio

In all three forms of date palm waste (fiber bundles, ash and biochar), C/N ratio has a rather high value. Therefore, any of these forms of waste (biochar is preferred) can be used for maintaining this ratio within its desired range in the soil and in fish and shrimp farming ponds, depending on the expertise of an experienced field specialist.

The percentages of constituent elements in the biochar of date palm waste in its commercial production, which is the right option in making use of this biomass, can be mentioned on their packaging for warning and to avoid any misuse.

Green Sorbent

It has been substantiated that biochar is a functional green sorbent (Lehmann *et al.,* 2011). Great amounts of biochar can be produced by applying pyrolysis process on date palm wastes to meet demands for recycling polluted waters, which is currently a major environmental concern.

Experimental data obtained through this investigation reveal that data palm wastes are valuable biomass, and their derived biochar is effective in soil improvement (fertilizing and restoring) and recycling polluted water. Proper utilization of these wastes can help reduce greenhouse gases emitted from their natural decomposition.

Further investigations are recommended on developing the uses of biochar and on refining pyrolysis derived vinegar out of palm waste for their applications in producing liquid fertilizer or drug items.

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