Advanced Sustainable BIOfuels for Aviation

Deliverable D2.2: Results and product characterization, for both woody and agro-residue chars. Mix of biochar and compost ready for preliminary tests (Task 2.1)

Consortium:

Acronym	Legal entity	Role
RE-CORD	CONSORZIO PER LA RICERCA E LA DIMOSTRAZIONE SULLE ENERGIE RINNOVABILI	CO
TRC	TOTAL RAFFINAGE CHIMIE SA	BEN
TRF	TOTAL RAFFINAGE FRANCE	BEN
SKYNRG	SKYENERGY BV	BEN
CENER	FUNDACION CENER-CIEMAT	BEN
ETA	ETA – Energia, Trasporti, Agricoltura Srl	BEN
CCE	CAMELINA COMPANY ESPANA S.L.	BEN
JRC	JOINT RESEARCH CENTRE – EUROPEAN COMMISSION	BEN

CO…Coordinator, BEN…Beneficiary

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PRO	Technical/economic progress report (internal work package reports indicating work status)	
DEL	Technical reports identified as deliverables in the Description of Work	**x**
MoM	Minutes of Meeting	
MAN	Procedures and user manuals	
WOR	Working document, issued as preparatory documents to a Technical report	
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Dissemination Level		
PU	Public	**x**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	
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1 Summary

The present deliverable titled "*Results and product characterization, for both wood and agro-residue chars. Mix of biochar and compost ready for preliminary tests (Task 2.1)*" illustrates the work performed on biochar by Consorzio Re-Cord (REC) in Work Package 2 as a partner of the BIO4A project.

Biochar was produced from two lignocellulosic feedstocks: Chestnut (*Castanea sativa* Mill.) and Wheat Straw (*Triticum aestivum* L.) through slow pyrolysis. Both feedstock and resulting products were chemically and physically characterized.

Products obtained resulted with different features, mainly in terms of carbon and ash content in weight – dry basis - and in terms of porosity (specific surface area, BET analysis).

Wood biochar, as expected, proved to be a high quality biochar due to its specific surface area (almost double compared to wheat straw biochar), to its higher amount of fixed carbon (+25.6 %) and lower ash content (-71.8 %).

The chestnut biochar produced was further used in BIO4A for the agronomic field tests in Spain in collaboration with Camelina Company España (CCE) within the framework of WP2.
In the field tests in Spain, chestnut biochar was used as follows:

a) for direct use as a soil amendment
b) for co-composting operations with the solid fraction of biogas digestate to obtain various lots of COMBI, which was also used as a soil amendment in the field tests.

The first batch of the above mentioned chestnut biochar and COMBI was shipped to Spain - in advance from the deadline scheduled for the present deliverable D2.2. (November 2018 instead of April 2020) - to allow timely beginning of agricultural operations for the agricultural campaign 2018/2019, related to the field tests on biochar, COMBI and *Camelina sativa* performed by Camelina Company España.

2 Biochar production

2.1 Biochar production from wood feedstock

2.1.1 Wood feedstock characterization

Figure 2The feedstock used for wood biochar production was chestnut (*Castanea sativa* Mill.) chips, which main chemical and physical characterization is provided in Table 2.

Table 1: Feedstock - Wood chip characterization [1].

Parameter	U.M.	Value	Method
Typology	-	hardwood	-
Timber	-	chestnut	-
Bulk density	kg m^{-3} w.b.	213.0	EN 15103
Size class	-	P35.1	EN 14961–1
LHV	MJ kg^{-1}	18.4	EN 14918
Water content	% w/w w.b.	13.2	EN 14774–2
Volatile matter	% w/w d.b.	74.2	EN 15148
Fixed carbon	% w/w d.b.	25.1	-
Ash	% w/w d.b.	0.7	EN 15148
Total C	% w/w d.b.	49.7	EN 15104
Total H	% w/w d.b.	5.3	EN 15104
Total N	% w/w d.b.	0.2	EN 15104

Total O	% w/w d.b.	44.5	EN 15104

2.1.2 Biochar production from wood feedstock

Biochar was produced in June 2018 in the oxidative CarbOn pilot plant developed by RE-CORD, described in the following paragraph.

Such production took place before the modifications mentioned in deliverable D2.1 [2] in order to produce COMBI in time for the agricultural season 2018/2019, allowing an additional year for the field experimentation with *Camelina sativa* in cooperation with CCE.

CarbOn is a continuous biomass carbonization system based on open top, downdraft technology, operating under oxidative pyrolysis regime. The plant is rated for 50 kg h^{-1} of biomass with up to 20 % w/w moisture content at inlet. The reactor is externally insulated and consists of a cylindrical volume where biomass is converted in a controlled oxidative environment in the temperature range of 500-750°C, with a solid residence time of approx. 3 h in the reactor and 2 h in the cooled discharge. A more detailed description of the process and the pilot plant can be found in references [1, 3].

The experimental conditions during biochar production in the CarbOn unit are reported in Table 2.

Table 2: Experimental conditions for biochar production in the CarbOn pilot unit [1].

Operating condition	Slow oxidative pyrolysis
Inlet feed	50 $kg_{w.b.}$ h^{-1}
Maximum process temperature	550°C
Residence time	3 h

The CarbOn pilot plant is a continuous biomass carbonization system based on open top downdraft design, borrowed from established gasification technology, operating in autothermal pyrolysis in the temperature range of 450 – 700°C and equivalence ratio (ER) between 0.1-0.2. Figure 1 reports the process flow diagram and a side view of the unit. The pilot is essentially composed of three sections: (1) loading and conversion of biomass; (2) charcoal discharge and cooling system; (3) extraction and combustion of evolved volatiles (vapors and permanent gases). The plant, made in stainless steel (AISI 304 and 316) and supported on a self-standing 6 x 2.5 m frame, is rated for 50 kg·h^{-1} of biomass with up to 20 wt.% moisture content.
The design of the pilot plant was granted the Italian Patent IT1429282, in the as-built version before the modifications described in Deliverable D2.1 [1].

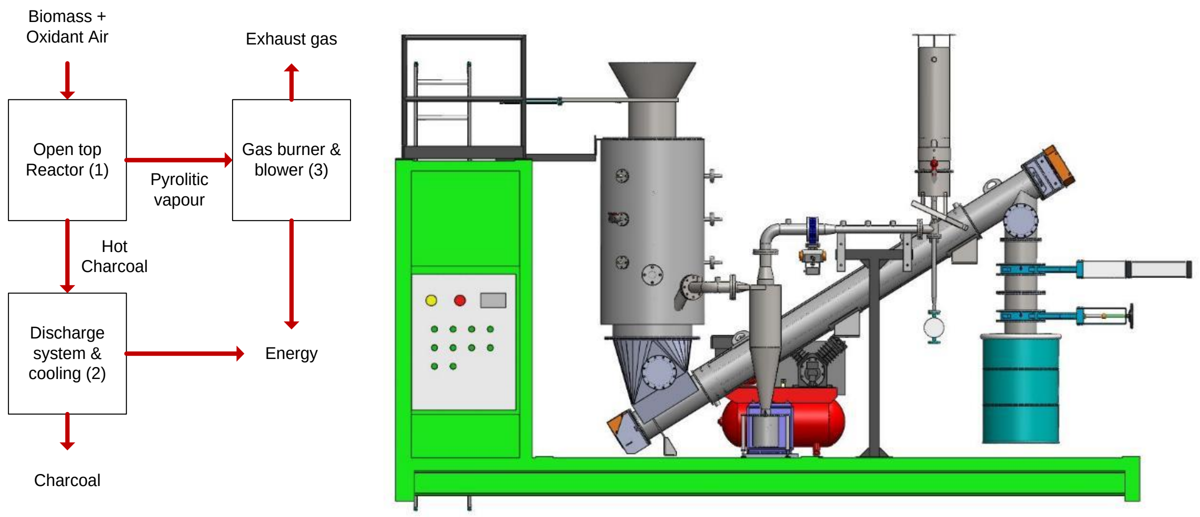

Figure 1: PFD (left) and side view (right) of CarbOn pilot unit.

2.1.3 Wood biochar characterization

The product obtained from CarbOn plant (Figure 2) was sampled according to EBC standards.

Figure 2: Wood biochar produced with chestnut chips

The following table shows the results of the analysis for biochar characterization (Table 3).

Table 3: Wood biochar chemical-physical characterization.

Parameter	U.M.	Value	Method
Typology	-	Chestnut	-
HHV	MJ kg^{-1}	-	-
LHV	MJ kg^{-1}	30.8	EN 14918
Water content	% w/w a.d.	5.0	UNI EN ISO 18134-2
Volatile matter	% w/w d.b.	14.5	UNI EN ISO 18123
Fixed carbon	% w/w d.b.	80.8	calculated
Ash	% w/w d.b.	4.7	UNI EN ISO 18122
Total C	% w/w d.b.	86.2	UNI EN ISO 16948
Total H	% w/w d.b.	2.1	UNI EN ISO 16948
Total N	% w/w d.b.	0.6	UNI EN ISO 16948
Total S	% w/w d.b.	0.04	ASTM D4239
Specific surface area (BET)	m^2 g^{-1}	216	ASTM D6556

In addition to the evaluation of the total surface (Nitrogen-based BET method) for surface and porosity characterization, a density functional theory (DFT) analysis was also performed to assess the pore size distribution (Figure 3).

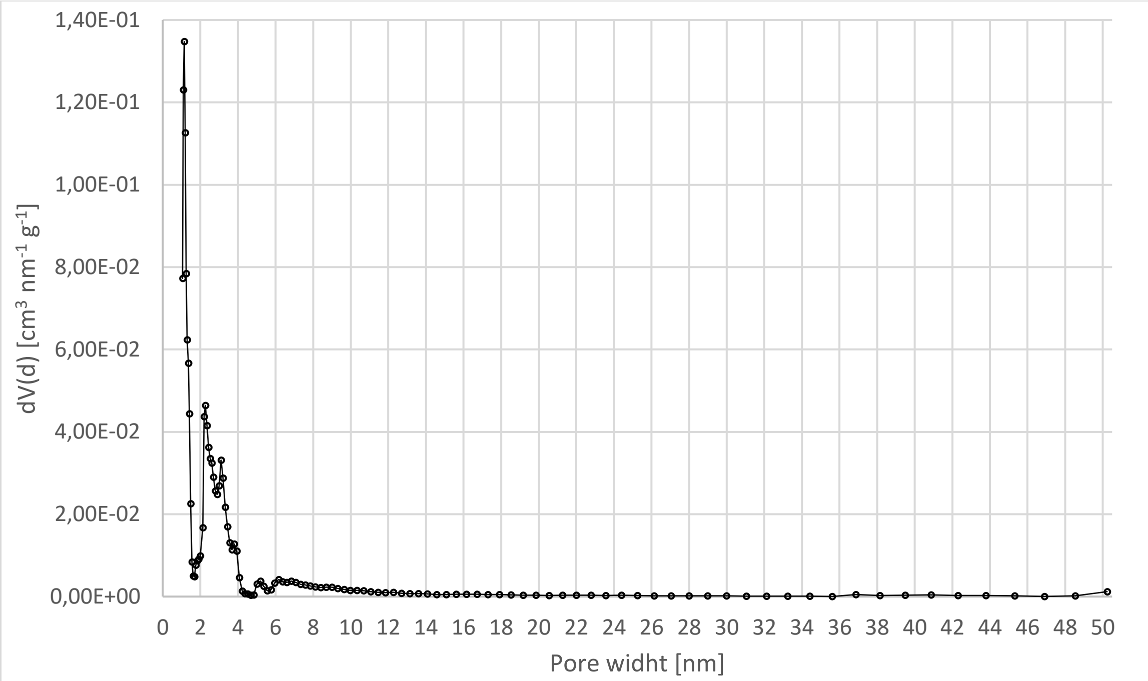

Figure 3: DFT curve on pore size distribution for biochar from *Castanea sativa* Mill.

The results in Table 3 show a biochar with a high content both of C and fixed carbon by weight (dry basis), meaning the wood feedstock has been well converted by the pyrolysis process. The total ash value resulting is quite low and representative of the wood biochar class of product. The specific surface area value obtained by BET analysis resulted 216 m^2 g^{-1}, with a biochar porosity structure mainly composed by micropores having diameters lower than 2 nm, and mesopores with diameters mainly ranging from 2 to about 4 nm (as shown in Figure 3).

2.2 Agro-residue biochar production

2.2.1 Biochar production from wheat straw

The feedstock used for agro-residue biochar production was Wheat (*Triticum aestivum* L.) straw. The choice came upon this specific biomass for the large availability and representativity of on-farm conditions in Southern Europe as an agro-residue, where wheat is a commonly cultivated cereal.
For the purpose of the BIO4A project, wheat straw was sourced in normal field conditions, from a local farm in Tuscany. Main chemical and physical characterization is given in Table 4.

Table 4: Feedstock – Wheat straw chemical-physical characterization.

Parameter	**U.M.**	**Value**	**Method**
Typology	-	Wheat straw	-
HHV	MJ kg^{-1}	18.71	UNI EN ISO 18125
LHV	MJ kg^{-1}	17.53	UNI EN ISO 18125
Water content	% w/w a.d.	8.6	UNI EN ISO 18134-2
Volatile matter	% w/w d.b.	74.6	UNI EN ISO 18123
Fixed carbon	% w/w d.b.	18.7	calculated
Ash	% w/w d.b.	6.7	UNI EN ISO 18122
Total C	% w/w d.b.	46.9	UNI EN ISO 16948
Total H	% w/w d.b.	5.7	UNI EN ISO 16948
Total N	% w/w d.b.	0.6	UNI EN ISO 16948
Total O	% w/w d.b.	0.2	ASTM D4239

2.2.2 Biochar production from agro-residue (wheat straw) feedstock

For the analytical purposes of this deliverable D2.2., biochar was obtained in TGA (LECO TGA 701) (Figure 4) under nitrogen flow at 10 liters per minute. This instrument, consisting of 19 ceramic crucibles, allows process temperatures up to 1000 °C, with the possibility to control the heating rate and plateau duration at maximum process temperature desired. In addition, it allows mass measurement with sensitivity up to 0.1 mg.
Calvelo Pereira et al. showed how the Thermo-Gravimetric Analysis (TGA) can be a suitable and practical mean to evaluate both the stable and the labile carbon fractions (respectively fixed carbon and volatile matter content of biochar) [14–16].

Figure 4: Wheat straw feedstock in LECO TGA 701.

The operating conditions used for biochar test production are presented in Table 5:

Table 5: Operating condition for biochar production from straw

Operating condition	**TGA LECO 701**
Heating rate	20 °C min^{-1}
Maximum process temperature	550 °C
Plateau duration at maximum temperature	2 h

2.2.3 Wheat straw biochar characterization

The biochar produced from wheat straw (Figure 5) was characterized for the main physical-chemical parameters. Results are shown in Table 6:

Table 6: Agro-residue biochar chemical-physical characterization.

Parameter	**U.M.**	**Value**	**Method**
HHV	MJ kg^{-1}	26.13	UNI EN ISO 18125
LHV	MJ kg^{-1}	25.74	UNI EN ISO 18125
Water content	% w/w d.b.	1.2	UNI EN ISO 18134-2
Volatile matter	% w/w d.b.	11.9	UNI EN ISO 18123
Fixed carbon	% w/w d.b.	64.3	calculated
Total ash	% w/w d.b.	23.8	UNI EN ISO 18122
Total C	% w/w d.b.	69.1	UNI EN ISO 16948
Total N	% w/w d.b.	1.0	UNI EN ISO 16948
Total H	% w/w d.b.	1.9	UNI EN ISO 16948
Total S	% w/w d.b.	0.4	ASTM D4239
Specific surface area (BET)	m^2 g^{-1}	118	ASTM D6556

Figure 5: Biochar produced from wheat straw

As done for the wood biochar produced, in addition to the evaluation of the total surface (Nitrogen-based Brunauer–Emmett–Teller BET method) for surface and porosity characterization, a density functional theory (DFT) model analysis was also performed to assess the pore size distribution (Figure 6).

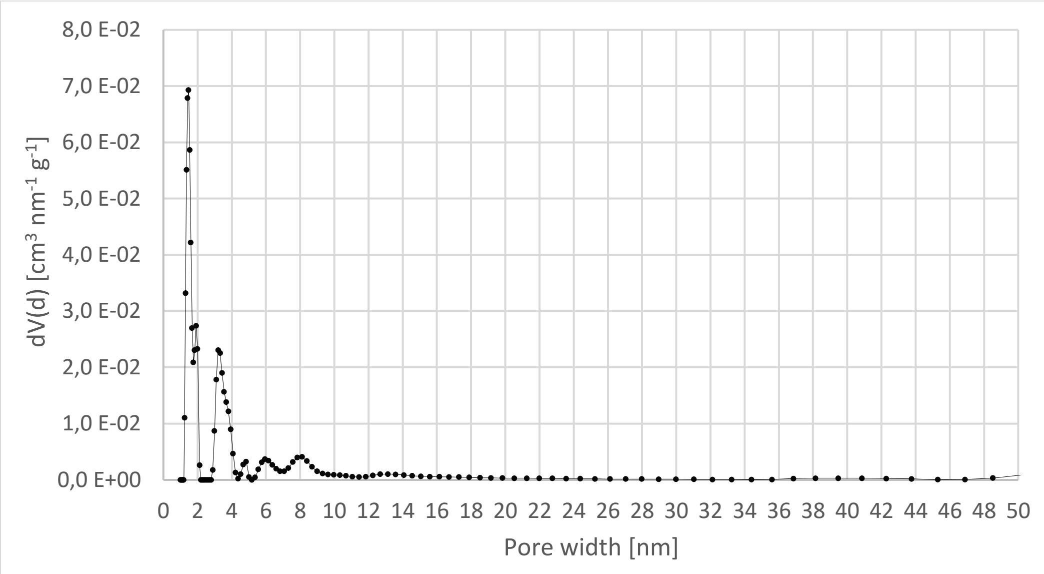

Figure 6: DFT curve on Pore size distribution for wheat straw biochar

The results in Table 6 show a biochar with a high content both of C and fixed carbon by weight, dry basis. The total ash value resulted is very high and representative of the straw biochar class of product.
The specific surface area value obtained by BET analysis resulted in 118 m^2 g^{-1}, with a biochar porosity structure mainly composed by micropores having diameters lower than 2 nm, and mesopores with diameters mainly ranging from 2 to about 4 nm (as shown in Figure 6).

2.3 Comparison

Two biochars were produced from different feedstocks: Chestnut (wood) and Wheat straw (agro-residue). Products obtained showed wdifferent characteristics, mainly in terms of carbon and ash content in weight – on dry basis - and in terms of porosity (specific surface area, BET analysis).
Wood biochar, as expected, proved to be a high quality biochar due to its specific surface area (almost double compared to wheat straw biochar), to a higher amount of fixed carbon (+25.6 %) and a lower ash content (-71.8 %).

Biochar is composed mainly by Carbon very stable to thermochemical and biological degradation, only marginally subject to mineralization by microorganisms [13, 14]. As reported by Leng et al, Biochar Fixed Carbon (BFC) is closely related to stable C content.
A higher fixed carbon content can thus be positively correlated with a high capacity of biochar to permanently sequester atmospheric carbon in soil.
A higher specific surface area is generally regarded as positively correlated with Water Holding Capacity when biochar is used as a soil amendment: however, pore distribution within micro, meso and macropores is also an important aspect to consider.
Biochar from wood feedstock, being chestnut a perennial plant, as expected, showed a higher total number of pores with a higher presence of mesopores.

However, practical conclusions on which feedstock is to be preferred to amend agricultural soil with biochar could be drawn only through randomized comparison in agronomic field tests on characterized soils.

Chestnut biochar characterized in this deliverable D2.2. has been used both directly and in COMBI production (described below) for the agricultural field tests in Spain performed in collaboration with CCE. Such field tests are currently generating important data to understand such relationship.

3 COMBI production

COMBI was produced through co-composting blends of chestnut biochar described in chapter 2 with solid fraction of digestate issued from a biogas plant, and the addition of a small and variable (for the different cases) amount of cereal straw as bulking agent.

3.1 Feedstock characterization

Analytical characterization of feedstock and products have been carried out according to the main European methods for biochar and compost as agricultural soil amendments; in particular, the European Biochar Certification (EBC) methods and the European Compost Network Quality Standards (ECN-QAS) [4, 5] were adopted.

3.1.1 Biochar

Table 7: Biochar characterization following EBC standards.

Parameter	U.M.	Threshold [4]	Value	Method
Bulk density	kg m^{-3}	-	146.0	EN 15103
pH	-	-	7.97	ISO 10390
Water content	% w/w d.b.	-	5.0	EN 14774-2
Volatile matter	% w/w d.b.	-	14.5	EN 15148
Fixed carbon	% w/w d.b.	-	80.8	EN 1860-2
Total ash	% w/w d.b.	-	4.7	EN 14775
Total C	% w/w d.b.	-	86.2	EN 15104
Organic C (C_{ORG})	% w/w d.b.	≥ 50	80.5	-
Inorganic C	% w/w d.b.	-	0.3	EN 13654-2
Molar H/C_{ORG}	-	≤ 0.7	0.29	-
Molar O/C_{ORG}	-	≤ 0.4	0.10	-
Total N	% w/w d.b.	-	0.6	EN 15104
Total H	% w/w d.b.	-	2.1	EN 15104
Total S	% w/w d.b.	-	0.04	EN 15104
Total P	mg kg^{-1}	-	b.d.l.	EN 15290
Total K	mg kg^{-1}	-	5259	EN 15290
Total Mg	mg kg^{-1}	-	851	EN 15290
Total Ca	mg kg^{-1}	-	9073	EN 15290
Specific surface area (BET)	m^2 g^{-1}	> 150 m^2 g^{-1} (preferred)	216	ASTM D6556
Heavy metals, metalloids and other elements	mg kg^{-1}	Premium grade:[1] Pb < 120 Cd < 1 Cu < 100 Ni < 30[2] Zn < 400 Cr < 80	 Pb = b.d.l. Cd = b.d.l. Cu = b.d.l. Ni = b.d.l. Zn = b.d.l. Cr = b.d.l.	EN 15290

[1] Premium Grade following Switzerland's Chemical Risk Reduction Act (ChemRRV) on recycling fertilizers.

[2] Biochars with Ni contamination < 100g mg kg-1 are permitted for composting purposes only if complying with the valid threshold for finished compost.

PAHs[3]	mg kg^{-1}	Premium grade:[4] < 4	1.14	DIN CEN TS 16181
LHV	MJ kg^{-1}	-	30.8	EN 14918

The characterization of the biochar produced and used in the present study confirms that it qualifies for the EBC premium grade quality.

3.1.2 Solid fraction of digestate

As regards the collection of Organic Matter (OM) for subsequent co-composting with biochar, digestate was supplied by an industrial anaerobic digestion plant located in the North of Italy, mainly fed with manure as main feedstock (Figure 7). The characterization of the digestate is reported in the Table 8.
The analysis of the Potential Dynamic Respirometric Index (PDRI) of the digestate suggests a well-stabilized organic matrix available at the outlet of the anaerobic process, collected after mechanical dewatering

Table 8: Feedstock - Digestate (solid fraction) characterization.

Parameter	**U.M.**	**Value**	**Method**
pH	-	7.0	CNR IRSA 1 Q64 Vol 3 1985
Water content	% w/w w.b.	63.0	EN 14346
Organic matter	% w/w d.b.	86.9	CNR IRSA 2 Q64 Vol 2 2008
Ash	% w/w d.b.	13.1	CNR IRSA 2 Q64 Vol 2 2008
Total C	% w/w d.b.	43.7	EN 15104
Total H	% w/w d.b.	5.4	EN 15104
Total N	% w/w d.b.	1.2	EN 15104
Total S	mg kg^{-1} d.b.	511	ASTM D4239
PDRI	mg O_2 kg_{OM}^{-1} h^{-1}	310	UNI 11184
Salmonella spp.	-	absence	
Escherichia Coli	UCF g^{-1}	<10	

Figure 7: Solid fraction of digestate used for co-composting

[3] Total Poly-aromatic Hydrocarbons (PAHs) (sum of 16 US EPA PAHs).
[4] Premium grade corresponds to the PAH threshold defined in the Swiss Chemical Risk Reduction Act (ChemRRV).

The water content of the solid fraction of the digestate was also a key parameter to be analysed: it was measured at 63% w/w. According to applicable standards, the presence of pathogens (*Salmonella spp.* and *Escherichia Coli*) also needed to be assessed, but no biological contamination was detected.

3.1.3 Cereal straw

The characterization of cereal straw (Figure 8), which was previously used in horse bedding stable, is detailed in Table 9.

Table 9: Feedstock - Straw characterization

Parameter	U.M.	Value	Method
Water content	% w/w w.b.	44.0	UNI EN 14774-3
Volatile matter	% w/w d.b.	69.6	UNI EN 15148
Fixed carbon	% w/w d.b.	18.5	UNI EN 15148
Ash	% w/w d.b.	11.9	UNI EN 14775
Total C	% w/w d.b.	42.5	UNI EN 15104
Total H	% w/w d.b.	5.1	UNI EN 15104
Total N	% w/w d.b.	1.2	UNI EN 15104
Total S	% w/w d.b.	0.2	ASTM D4239

Figure 8: Cereal straw used as bulking agent

3.2 Co-composting process

The co-composting process adopted in the present work followed the ECN-QAS recommended procedures [5] and was performed during the 2018 summer season in a farm located in Scandicci (Florence), Italy.
The experiment duration was 60 days, with no additional curing time also keeping into account the time constraints for the planned soil application operations (November 2018) of field agronomic trials in Spain, performed in collaboration with CCE.
The composting system adopted for the present work was static, with windrows formed within a farm-greenhouse (Figure 10), and manually turned twice per week.

All windrows were prepared for the test at the same time and in the same environment by the same operators; samples for analysis were taken at day 0 and day 60. Windrows dimensions were approximately 2 m (length) x 1.6 m (width) x 0.8 m (height), creating a pile of about 1.5 m^3 of volume with a vertical section as similar as possible to a semicircular shape.

Windrows were prepared starting from a first layer of digestate and finishing them with digestate covering the entire pile. Biochar and straw layers were separated by digestate layers. At the end of the windrows preparation, all piles accounted for the same volume. This layer configuration lasted until the first turning, which occurred after a week. Temperatures were collected before windrow turning by positioning three probes in each pile at 1/3rd of the vertical section from the soil and at 1/4th, half and 3/4th of the horizontal section.

Ambient temperature and humidity were not recorded inside the greenhouse due to practical constraints. However, in Figure 5 (online resource) the average daily temperature and relative humidity of Scandicci (Florence, Italy) are reported, taking data from the meteorological station managed by SIR (Servizio Idrologico della Regione Toscana), an organizational unit of the Tuscany Region, are reported. Daily average temperature and daily average relative humidity values are compared to average windrow temperature.

The daily average values of temperature and relative humidity at the meteorological station can be a good approximation of those at the greenhouse, because of their physical proximity (Scandicci, Florence, Italy), and the greenhouse itself can be considered as an open tunnel (as shown in Figure 9).

Figure 9: farm-scale co-composting site (Scandicci, Floremce, Italy)

Figure 10: Windrows and piles.

Four different blends were considered for composting, one for each windrow (Figure 10). The rates of biochar were increased from 0% to 15.2% by weight on dry basis, for reasons related to the experimental design of field rate application. Correspondingly, the rates of straw and digestate were decreased, keeping the initial goals of four windrows with the same volume.
The windrows were named CD (Digestate and straw only) CB1 (Digestate, straw and 12 kg w.b. of biochar), CB2 (Digestate, straw and 18 kg w.b. of biochar) and CB3 (Digestate, straw and 24 kg w.b. of biochar), as detailed in Table 10.
The 18 kg w.b. rate of biochar was selected for CB2, as it corresponds to an application rate of 3 t ha^{-1} w.b. of biochar for the case of agronomic field trials in 60 m^2 plots. The 12 kg w.b. and 24 kg w.b. rate of biochar for CB1 and CB3, respectively, were used to investigate the effects of different doses of biochar in windrows. The biochar percentage by weight - on dry basis - of the starting composting piles is thus mainly related to the digestate humidity - as received.

Table 10: Initial windrows compositions

	U.M.	CD	CB1	CB2	CB3
Windrow	kg d.b.	160.6	156.5	153.0	149.6
Starting moisture	% w/w w.b.	61.6	60.0	59.2	58.3
Biochar content	kg w.b.	0.0	12.0	18.0	24.0
Biochar rate	% w/w d.b.	0.0	7.3	11.2	15.2
C/N index		36.3	40.4	42.7	45.2

The measured C/N index of the CD pile was equal to 36.3, close to the optimal value for composting reported in literature [6, 7]; in general, higher C/N values of the initial matrix can lead to extend the duration of the composting process[8]. Compared to the control C/N ratio (i.e. the C/N value for the CD pile), the others piles (CB1, CB2 and CB3) showed higher ratios, increasing with the addition of the biochar, which however gives the main contribution in terms of stable and recalcitrant C.
The measured initial moisture content falls within the range indicated by literature, i.e. between 50 and 60 % in mass fraction [7, 9, 10].

While the pH of the digestate, the main substrate matrix, was equal to 7.00, the pH of biochar was 7.97; this contributed to an optimum environment for microbiological activity, as also reported by de Bertoldi et al., that explained how pH > 7.5 can lead to higher amount of ammonia volatilization [11, 12].
The presence of coliforms, as *E.Coli*, was also investigated in the digestate and the different composted products: this analysis was carried out according to APAT CNR IRSA 7030 F Man 29 2003 method. Finally, humic substances content was assessed according to the Regione Piemonte method C 6.3-1998.
Replications of windrows were not possible due to time, space constraints in the greenhouse and availability of feedstock on short notice.
Nevertheless, COMBI was properly sampled at the end of the co-composting process (it was turned manually by operators twice per week) taking sample material from different sections and all along the length of every windrow: three vertical sections were chosen to collect material for analysis (the ones where temperatures probes are located, as described before). Furthermore, the material collected for every section was taken at different height, considering also the external layer. After samples homogenization, they were analysed in Re-Cord laboratory following relative standards for all the analysis chosen (where triplicates are required in most of the cases), following the ECN-QAS quality scheme.

3.3 Products shipment for field trials in Spain

A first batch of COMBI and chestnut biochar was shipped to Spain in November 2018 for the for the agronomic field tests within the framework of WP2.

Figure 11: COMBI blends (left) and chestnut biochar (right) shipment to CCE partner for field trials

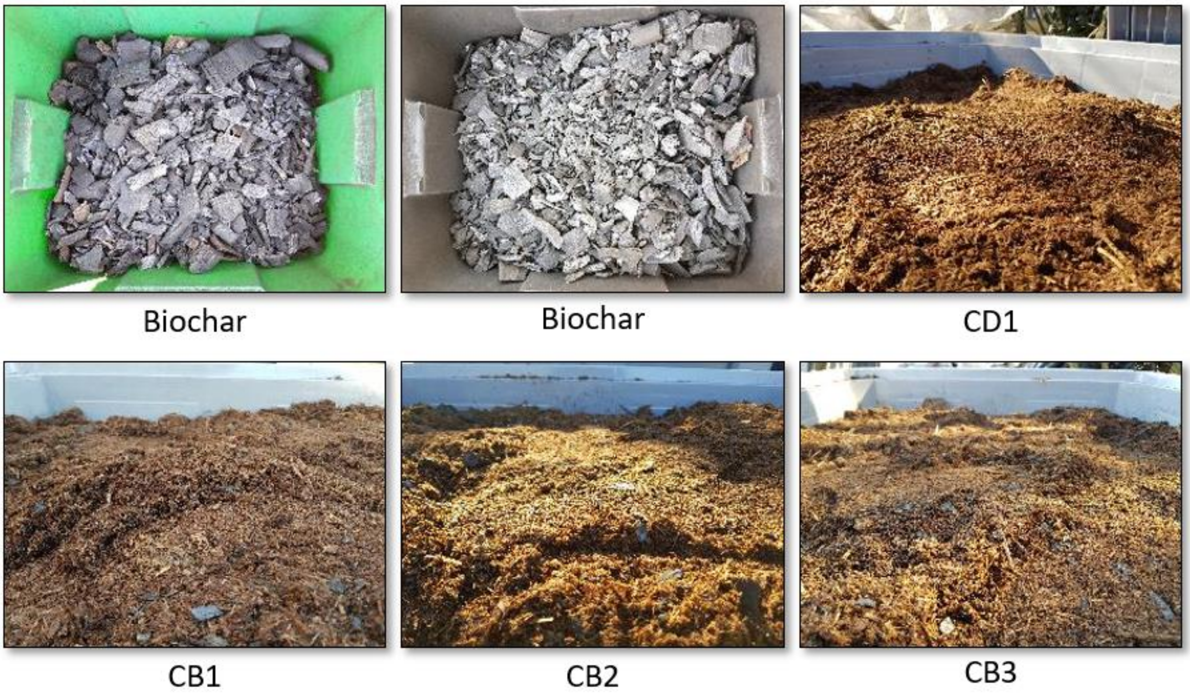

Figure 12: Biochar and combi blends ready for shipment

4 Conclusions

Wood biochar, as expected, proved to be a high quality biochar due to its specific surface area (almost double compared to wheat straw biochar), to its higher amount of fixed carbon (+25.6 %) and lower ash content (-71.8 %).
However, practical conclusions on which feedstock is to be preferred to amend agricultural soil with biochar could be drawn only through randomized comparison in agronomic field tests on characterized soils.
Chestnut biochar characterized in this deliverable D2.2. has been used both directly and in COMBI production (described above) for the agricultural field tests in Spain performed in collaboration with CCE. Such field tests are currently generating important data to understand the interaction between biochar and soil.

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