

## Quality of the pellets obtained with wood and cutting residues of stone pine (*Pinus pinea* L.)

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### Supplementary Material

**Table S1.** Specification of wood pellet classes for commercial and residential uses (ISO 17225-2) [49].

Property	Standard	A1	A2	B
Origin and source	ISO 17225-1	1.1.3 Stem wood 1.2.1 Residues / remains of wood not chemically treated	1.1.1 Whole trees 1.1.3 Stem wood 1.1.4 Logging residues 1.2.1. Residues / remains of wood not chemically treated	1.1 Forest plantation and other virgin wood 1.2 By-products and residues 1.3.1 Used wood not chemically treated
Diameter and length, D and L (mm)	ISO 17829	D06, 6 ± 1; 3.15 ≤ L ≤ 40	D06, 6 ± 1; 3.15 ≤ L ≤ 40	D06, 6 ± 1; 3.15 < L < 40
Moisture, M (w-%)	ISO 18134-1 ISO 18134-2	M10 ≤ 10	M10 ≤ 10	M10 ≤ 10
Ash, A (w-%)	ISO 18122	A0.7 ≤ 0.7	A1.2 ≤ 1.2	A2.0 ≤ 2.0
Durability, DU (w-%)	ISO 1783-1	DU98.0 ≥ 98.0	DU97.5 ≥ 97.5	DU96.5 ≥ 96.5
Fines, F (w-%)	EN 15210-1	F1.0 ≤ 1.0	F1.0 ≤ 1.0	F1.0 ≤ 1.0
Net calorific value, Q (MJ/ kg, kWh/kg)	ISO 18125	Q ≥ 16.5 Q ≥ 4.6	Q ≥ 16.5 Q ≥ 4.6	Q ≥ 16.5 Q ≥ 4.6
Bulk density, BD (kg/m <sup>3</sup> )	ISO 17828	600 ≤ BD ≤ 750	600 ≤ BD ≤ 750	600 ≤ BD ≤ 750
Nitrogen, N (w-%)	ISO 16948	N0.3 ≤ 0.3	N0.3 ≤ 0.3	N0.3 ≤ 0.3
Sulfur, S (w-%)	ISO 16994	S0.04 ≤ 0.04	S0.04 ≤ 0.04	S0.05 ≤ 0.05
Chlorine, Cl (w-%)	ISO 16994	Cl0.02 ≤ 0.02	Cl0.02 ≤ 0.02	Cl0.03 ≤ 0.03

Only the values of the properties studied in the article are included

Reference is only made to pellets with a diameter of 6 mm and not to those of 8 mm.

**Table S2.** Specification of the classes of wood pellets for industrial use. (ISO 17225-2) [49]

Property	Standard	I1	I2	I3
Origin and source	ISO 17225-1	1.1 Forest plantation and other virgin wood 1.2.1. Residues / remains of wood not chemically treated	1.1 Forest plantation and other virgin wood 1.2.1. Residues / remains of wood not chemically treated	1.1 Forest plantation and other virgin wood 1.2 By-products and residues 1.3.1 Used wood not chemically treated
Diameter and length, D and L, (mm)	ISO 17829	D06, 6 ± 1; 3.15 ≤ L ≤ 40	D06, 6 ± 1; 3.15 ≤ L ≤ 40	D06, 6 ± 1; 3.15 < L < 40
Moisture, M, (w-%)	ISO 18134-1 ISO 18134-2	M10 ≤ 10	M10 ≤ 10	M10 ≤ 10
Ash, A, (w-%)	ISO 18122	A1.0 ≤ 1.0	A1.5 ≤ 1.5	A3.0 ≤ 2.0
Durability (DU, w-%)	ISO 1783-1	97.5 ≤ DU ≤ 99.0	97.0 ≤ DU ≤ 99.0	96.5 ≤ DU ≤ 99.0
Fines (F, w-%)	EN 15210-1	F4.0 ≤ 4.0	F5.0 ≤ 5.0	F6.0 ≤ 6.0
Net calorific value, Q, (MJ/ kg)	ISO 18125	Q16.5 ≥ 16.5	Q16.5 ≥ 16.5	Q16.5 ≥ 16.5
Bulk density, BD, (kg/m <sup>3</sup> )	ISO 17828	BD600 ≥ 600	BD600 ≥ 600	BD600 ≥ 600

Only the values of the properties studied in the article are included

Reference is only made to pellets with a diameter of 6 mm and not to those of 8 mm.

**Table S3.** Granulometric distribution of the sawdust used in the tests for each type of biomass and sieve.

Particle size (mm)	NTW (5 mm)	BARK (5 mm)	MBR (5 mm)	DTTB (5 mm)	DTTB (3,5 mm)	DTTB (2 mm)
>3.15	4.25	8.53	18.93	16.65	5.35	0.30
2.8-3.15	14.72	13.67	15.61	18.24	16.58	3.52
2.0-2.8	16.47	17.98	18.95	13.56	12.27	6.29
1.4-2.0	19.68	18.34	14.96	14.55	14.50	23.05
0.1-1.4	15.10	14.11	10.75	14.01	17.22	21.34
0.5-1.0	15.78	12.35	11.65	12.49	16.50	19.50
0.25-0.5	10.09	10.70	6.51	7.61	13.03	17.41
<0.25	3.91	4.32	2.64	2.89	4.55	8.59

**Table S4.** Pellets properties (mean  $\pm$   $\sigma$ ) with different dies and types of stone pine biomass

	Yield (%)	Pellet moisture (%)	Durability (%)	Bulk density (kg/m <sup>3</sup> )	Pellet length (cm)	Particle density (kg/m <sup>3</sup> )
18NTW	62.8 $\pm$ 0.1	11.34 $\pm$ 0.01	64.3 $\pm$ 3.6	496.4 $\pm$ 2.6	1.09 $\pm$ 0.01	1064.6 $\pm$ 8.8
18BARK	80.3 $\pm$ 0.1	9.73 $\pm$ 0.06	63.3 $\pm$ 0.7	574.6 $\pm$ 5.2	0.99 $\pm$ 0.03	1084.0 $\pm$ 15.6
18MBR	98.9 $\pm$ 0.1	7.98 $\pm$ 0.16	93.6 $\pm$ 0.6	638.2 $\pm$ 7.7	1.79 $\pm$ 0.04	1217.5 $\pm$ 1.3
18DTTB	99.4 $\pm$ 0.1	4.49 $\pm$ 0.08	93.9 $\pm$ 0.7	669.6 $\pm$ 3.7	1.77 $\pm$ 0.10	1293.2 $\pm$ 24.4
20NTW	66.3 $\pm$ 0.1	11.44 $\pm$ 0.02	65.3 $\pm$ 0.6	495.5 $\pm$ 1.3	1.00 $\pm$ 0.02	1118.5 $\pm$ 10.1
20BARK	86.8 $\pm$ 0.1	11.46 $\pm$ 0.08	62.8 $\pm$ 1.1	569.1 $\pm$ 1.0	0.86 $\pm$ 0.04	1187.7 $\pm$ 38.5
20MBR	98.6 $\pm$ 1.4	8.43 $\pm$ 0.02	89.4 $\pm$ 1.3	638.2 $\pm$ 2.6	1.55 $\pm$ 0.03	1224.5 $\pm$ 23.0
20DTTB	99.5 $\pm$ 0.3	5.89 $\pm$ 0.97	95.2 $\pm$ 2.0	671.4 $\pm$ 3.1	1.75 $\pm$ 0.10	1280.2 $\pm$ 25.8
22NTW	72.0 $\pm$ 0.1	10.10 $\pm$ 0.01	66.66 $\pm$ 2.38	514.55 $\pm$ 5.16	0.97 $\pm$ 0.00	1066.1 $\pm$ 2.5
22BARK	94.8 $\pm$ 0.1	10.46 $\pm$ 0.69	72.64 $\pm$ 0.76	587.30 $\pm$ 2.55	0.76 $\pm$ 0.00	1094.4 $\pm$ 1.4
22MBR	99.3 $\pm$ 0.1	7.55 $\pm$ 0.01	94.28 $\pm$ 0.47	668.20 $\pm$ 1.27	1.79 $\pm$ 0.00	1246.5 $\pm$ 10.0
22DTTB	99.4 $\pm$ 0.2	7.20 $\pm$ 1.43	94.97 $\pm$ 1.06	639.10 $\pm$ 31.76	1.74 $\pm$ 0.16	1220.4 $\pm$ 27.0
24NTW	91.8 $\pm$ 0.1	8.75 $\pm$ 0.03	77.5 $\pm$ 1.9	574.6 $\pm$ 10.3	1.28 $\pm$ 0.05	1197.1 $\pm$ 80.0
24BARK	94.3 $\pm$ 0.2	8.91 $\pm$ 0.03	73.7 $\pm$ 1.3	651.0 $\pm$ 7.7	0.91 $\pm$ 0.03	1248.8 $\pm$ 1.4
24MBR	97.5 $\pm$ 0.1	4.35 $\pm$ 0.02	88.3 $\pm$ 0.3	696.4 $\pm$ 2.6	1.29 $\pm$ 0.01	1303.8 $\pm$ 1.8
24DTTB	99,6 $\pm$ 0,1	4,86 $\pm$ 0,82	92,5 $\pm$ 2,2	723,2 $\pm$ 3,5	1,38 $\pm$ 0,03	1320,1 $\pm$ 25,4

**Table S5.** Pearson correlation coefficients among the characteristics of the pellet samples of pine residues. The significant correlation values (<0.05) are depicted in bold.

Correlation Coefficients		Yield	Moisture	Durability	Bulk density	Pellet length	Particle density
Pearson Correlation	Yield	1.000	0.314	0.786	-0.145	0.361	-0.085
	Moisture	0.314	1.000	0.519	-0.925	0.745	-0.615
	Durability	0.786	0.519	1.000	-0.300	0.554	-0.337
	Bulk density	-0.145	-0.925	-0.300	1.000	-0.642	0.638
	Pellet length	0.361	0.745	0.554	-0.642	1.000	-0.460
	Particle density	-0.085	-0.615	-0.337	0.638	-0.460	1.000
Signification	Yield	-	<b>0.003</b>	<b>0.000</b>	0.179	<b>0.001</b>	0.430
	Moisture	<b>0.003</b>	-	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>
	Durability	<b>0.000</b>	<b>0.000</b>	-	<b>0.004</b>	<b>0.000</b>	<b>0.001</b>
	Bulk density	0.179	<b>0.000</b>	<b>0.004</b>	-	<b>0.000</b>	<b>0.000</b>
	Pellet length	<b>0.001</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	-	<b>0.000</b>
	Particle density	0.430	<b>0.000</b>	<b>0.001</b>	<b>0.000</b>	<b>0.000</b>	-

**Table S6.** Properties of stone pine wood pellets with different dies (18, 20, 22 and 24), moisture content (MOI, 1 = 11.5%, 2 = 14%, 3 = 16.5%) and particle sizes.

	Yield (%)	Pellet moisture (%)	Durability (%)	Bulk density (kg/m <sup>3</sup> )	Pellet length (cm)	Particle density (kg/m <sup>3</sup> )
18MOI1-SF	99.4 ± 0.1	4.49 ± 0.13	93.5 ± 0.2	671.8 ± 3.8	1.68 ± 0.05	1295.7 ± 39.1
18MOI1-SM	99.2 ± 0.2	6.49 ± 0.15	91.7 ± 1.2	639.1 ± 16.7	1.83 ± 0.03	1254.5 ± 14.4
18MOI1-SC	99.8 ± 0.1	7.19 ± 0.04	96.3 ± 0.1	623.7 ± 10.3	2.13 ± 0.01	1271.0 ± 21.9
18MOI2-SF	99.4 ± 0.1	4.50 ± 0.01	94.4 ± 0.6	667.3 ± 2.6	1.86 ± 0.01	1290.7 ± 15.4
18MOI2-SM	99.4 ± 0.2	6.96 ± 1.10	93.2 ± 1.7	622.7 ± 52.9	1.77 ± 0.16	1291.3 ± 52.8
18MOI2-SC	99.8 ± 0.1	9.06 ± 0.53	96.8 ± 0.0	604.6 ± 6.4	2.24 ± 0.02	1246.5 ± 5.9
18MOI3-SF	99.6 ± 0.1	4.51 ± 0.04	94.1 ± 0.1	678.2 ± 12.9	1.86 ± 0.04	1307.9 ± 10.0
18MOI3-SM	99.0 ± 0.3	4.26 ± 0.07	90.7 ± 1.4	680.9 ± 1.3	1.72 ± 0.03	1300.2 ± 16.2
18MOI3-SC	99.6 ± 0.2	11.68 ± 0.25	93.1 ± 1.1	512.7 ± 2.6	1.84 ± 0.01	1169.1 ± 35.9
20MOI1-SF	99.3 ± 0.2	5.06 ± 0.04	93.5 ± 0.5	672.7 ± 2.6	1.66 ± 0.01	1285.2 ± 35.1
20MOI1-SM	99.6 ± 0.1	6.14 ± 0.06	95.6 ± 0.4	660.0 ± 10.3	1.72 ± 0.03	1259.9 ± 7.9
20MOI1-SC	199.8 ± 0.3	6.35 ± 0.05	97.2 ± 0.1	664.6 ± 11.5	2.03 ± 0.01	1272.0 ± 3.1
20MOI2-SF	99.8 ± 0.1	6.73 ± 0.18	96.9 ± 0.4	670.0 ± 3.8	1.84 ± 0.05	1275.2 ± 25.7
20MOI2-SM	99.6 ± 0.2	6.66 ± 1.34	95.4 ± 1.1	663.3 ± 24.1	1.83 ± 0.09	1272.1 ± 12.1
20MOI2-SC	99.9 ± 0.1	8.70 ± 0.05	98.1 ± 0.1	630.0 ± 1.3	2.10 ± 0.02	1235.7 ± 26.0
20MOI3-SF	99.9 ± 0.1	7.97 ± 0.02	98.5 ± 0.1	648.2 ± 3.8	2.16 ± 0.02	1254.9 ± 3.9
20MOI3-SM	99.8 ± 0.1	6.27 ± 0.01	95.9 ± 0.1	680.0 ± 5.1	1.83 ± 0.04	1290.8 ± 2.0
20MOI3-SC	99.8 ± 0.1	10.07 ± 0.24	97.6 ± 0.1	585.5 ± 10.3	2.00 ± 0.01	1249.3 ± 49.8
22MOI1-SF	99.3 ± 0.2	6.00 ± 0.54	94.1 ± 0.5	666.4 ± 3.9	1.60 ± 0.01	1232.6 ± 14.2
22MOI1-SM	99.7 ± 0.1	6.36 ± 0.08	95.9 ± 0.2	648.2 ± 9.0	1.91 ± 0.03	1233.3 ± 15.0
22MOI1-SC	99.7 ± 0.1	6.19 ± 0.03	96.2 ± 0.1	661.9 ± 5.2	1.76 ± 0.04	1245.4 ± 27.1
22MOI2-SF	99.5 ± 0.2	8.41 ± 0.11	95.8 ± 0.6	611.9 ± 6.4	1.88 ± 0.02	1208.2 ± 37.2
22MOI2-SM	99.5 ± 0.3	7.73 ± 0.97	96.5 ± 1.1	637.6 ± 17.6	1.95 ± 0.24	1232.6 ± 25.5
22MOI2-SC	99.7 ± 0.1	7.50 ± 0.51	96.0 ± 0.3	601.0 ± 6.4	1.92 ± 0.04	1184.6 ± 10.9
22MOI3-SF	99.3 ± 0.2	8.95 ± 0.25	94.2 ± 0.1	580.9 ± 14.1	1.82 ± 0.05	1205.5 ± 27.5
22MOI3-SM	99.3 ± 0.3	5.01 ± 0.08	93.9 ± 0.6	664.6 ± 1.3	1.51 ± 0.02	1217.0 ± 27.4
22MOI3-SC	99.7 ± 0.1	10.64 ± 0.35	96.1 ± 0.1	557.3 ± 9.0	1.80 ± 0.01	1242.5 ± 9.8
24MOI1-SF	99.5 ± 0.2	1.15 ± 0.23	90.6 ± 0.0	724.6 ± 1.3	1.41 ± 0.03	1339.8 ± 17.3
24MOI1-SM	99.5 ± 0.1	2.67 ± 0.03	94.4 ± 0.1	694.6 ± 10.3	1.30 ± 0.01	1301.7 ± 24.9
24MOI1-SC	99.7 ± 0.1	3.19 ± 0.20	95.1 ± 0.3	698.2 ± 5.2	1.75 ± 0.01	1264.1 ± 18.1
24MOI2-SF	99.6 ± 0.1	2.59 ± 0.04	94.4 ± 0.4	721.9 ± 5.2	1.35 ± 0.02	1300.4 ± 8.8
24MOI2-SM	99.5 ± 0.1	2.09 ± 0.97	93.9 ± 0.7	720.6 ± 11.0	1.21 ± 0.08	1330.8 ± 27.5
24MOI2-SC	99.8 ± 0.1	5.41 ± 0.05	98.0 ± 0.0	670.0 ± 11.6	1.82 ± 0.02	1253.0 ± 14.2
24MOI3-SF	99.7 ± 0.1	2.59 ± 0.04	92.9 ± 0.1	714.6 ± 2.6	1.26 ± 0.02	1283.9 ± 15.3
24MOI3-SM	99.6 ± 0.2	3.12 ± 0.06	95.0 ± 0.2	720.9 ± 3.8	1.37 ± 0.03	1290.7 ± 15.8
24MOI3-SC	99.8 ± 0.1	6.61 ± 0.08	98.0 ± 0.1	660.9 ± 3.8	1.49 ± 0.01	1259.4 ± 8.1

**Table S7.** Pearson correlation coefficients among the characteristics of the pellet samples of debarked pine trunk. The significant correlation values (<0.05) are depicted in bold.

Correlation Coefficients		Yield	Moisture	Durability	Bulk density	Pellet length	Particle density
Pearson Correlation	Yield	1.000	0.314	0.786	-0.145	0.361	-0.085
	Moisture	0.314	1.000	0.519	-0.925	0.745	-0.615
	Durability	0.786	0.519	1.000	-0.300	0.554	-0.337
	Bulk density	-0.145	-0.925	-0.300	1.000	-0.642	0.638
	Pellet length	0.361	0.745	0.554	-0.642	1.000	-0.460
	Particle density	-0.085	-0.615	-0.337	0.638	-0.460	1.000
Signification	Yield	-	<b>0.003</b>	<b>0.000</b>	0.179	<b>0.001</b>	0.430
	Moisture	<b>0.003</b>	-	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>
	Durability	<b>0.000</b>	<b>0.000</b>	-	<b>0.004</b>	<b>0.000</b>	<b>0.001</b>
	Bulk density	0.179	<b>0.000</b>	<b>0.004</b>	-	<b>0.000</b>	<b>0.000</b>
	Pellet length	<b>0.001</b>	<b>0.000</b>	<b>0.000</b>	<b>0.000</b>	-	<b>0.000</b>
	Particle density	0.430	<b>0.000</b>	<b>0.001</b>	<b>0.000</b>	<b>0.000</b>	-