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Agronomic Evaluation of Ethiopian Mustard (*Brassica carinata* A. Braun) Germplasm and Physical-energy Characterization of Crop Residues in a Semi-arid Area of Sicily (Italy)

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Brassica carinata A. Braun is one of the most interesting oilseed crops suited to arid and semi-arid areas for energy purposes. Several studies have highlighted the possibility of introducing this species into cropping systems, typical of Mediterranean region. The aims of this study were to evaluate the agronomic performance of *Brassica carinata* germplasm under Mediterranean climatic conditions and to assess the physical and energy characteristics of crop residues and pellets made from the residues. A total of 20 different accessions of *Brassica carinata* were compared in a semi-arid area of Sicily (Italy). In the two-year test period, the main morphological and yield parameters of the accessions were recorded. Crop residues were characterized by determining the moisture content, the ash content and the gross calorific value. The crop residues were tested for pellet-making and the end product was analysed for its physical and energy properties by determining the ash content, gross calorific value and mechanical durability. For crop residues, differences were found to be highly significant for the moisture content and not significant for the gross calorific value. For pellet, differences were highly significant for all parameters in the study.

1. Introduction

Brassica carinata A. Braun (Ethiopian mustard) is a native herbaceous plant species of Eastern Africa and represents one of the most interesting oilseed crop for energy purposes in the Mediterranean region. The high yield levels, the ability to adapt and the resistance to abiotic and biotic stresses, in arid and semi-arid conditions, make this species particularly appreciated in terms of agronomic and energy balances as stated by Copani et al. (2009). Several studies have highlighted the possibility of introducing this species into cropping systems, typical of some Mediterranean countries, as an alternative to *Brassica napus*, mainly for reduced seed losses at harvest with respect to winter rapeseed (Cardone et al., 2003; Copani et al., 2009). In a study, when comparing the two species, Cardone et al. (2003) stated that *Brassica carinata* is more productive than *Brassica napus* both under low-input conditions and adverse environmental conditions. This concept was also confirmed by Stamigna et al. (2012). Ethiopian mustard is usually cultivated for its oil that is rich in erucic and linoleic acids and well-indicated for biofuels. Most of the literature on the energy uses of Ethiopian mustard focuses on the production of biodiesel (Cardone et al., 2003; Bouaid et al., 2005) and bioethanol (Gonzàlez-García et al., 2009) and there is little or no information on the use of agricultural residues of this species for energy purposes. The main reason is probably related to the energetic characteristics of agricultural residues compared to those of forestry residues. Literature highlights, in fact, that gross calorific values (GCV) of forestry residues are significantly higher than those of agricultural residues and the generation of heat and electricity too. Moreover a great disadvantage to using agricultural residues is crop seasonality that can create an unreliable biomass supply as claimed by Gravalos et al. (2016). However, despite some disadvantages, the conversion of agricultural residues to biomass feedstock for heat and electricity generation has become a common form of bioenergy as stated by Jiang et al. (2012). Agricultural residues, such as straw, after being

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pelletized, can represent a potential option for energy production, especially in the rural areas of the developing countries. In these areas, the development of herbaceous energy crops and the valorisation of their agricultural residues are considered as beneficial both to the environment, primarily through the reduction of atmospheric CO_2 concentrations and to the agricultural sector by helping to solve the problem of food surpluses and huge areas of crop land left abandoned. Agricultural residues can provide farmers with an opportunity to supplement their income and diversify production, an aspect sustained by energy and environmental policies which encourage and support their use as stated by Leto et al. (2011). In recent years, increasing attention has been paid to quantification of bioenergy potentials of agricultural residues. Matsumura et al. (2005) discussed the use of agricultural residues in Japan as an energy resource based on the amounts produced and availability. Fernandes and Costa (2010) evaluated the potential of biomass residues, both forestry and agricultural residues, in a region of Portugal. Valdez-Vazquez et al. (2010) examined the distribution and potential of bioenergy resources from agricultural activities of different crops in Mexico. Scarlat et al. (2010) provided a resource-based assessment of the available agricultural crop residues for bioenergy production in the European Union. Gregg and Smith (2010) quantified and characterized the potential of agricultural and forestry residues biomass for bioenergy use in a global scale. Duca et al. (2015) evaluated the quality of residues deriving from biodiesel chains based on agricultural crops such as Ethiopian mustard and cardoon. The aims of this study were to evaluate the agronomic performance of *Brassica carinata* germplasm in a semi-arid area of Sicily (Italy) and to assess the physical and energy characteristics of crop residues and pellets made from these residues.

2. Experimental

2.1 Description of the test site

The research was carried out from 2013 to 2015 at the “Calogero Amato Vetrano” Agricultural Technical Institute in Sciacca, a city (41,000 inhabitants) in the South-West of Sicily (110 m a.s.l., 37°30’43’’N,13°07’32,08’’E). The climate of the area is semi-arid with a mean annual rainfall of about 470 mm, mainly distributed between October and March, and with an average temperature of 18.1 °C. The soil type is sandy clay loam (Aric. Regosol, 45% sand, 26% silt and 29% clay) with a pH of 7.4, 15 g kg^{-1} organic matter.

2.2 Agronomic aspects

The seeds of *Brassica carinata* A. Braun were obtained from Plant Gene Resources of Canada (PGRC), Agriculture & Agri-Food Canada. A total of 20 different accessions of Ethiopian mustard were compared, more than 60%, of which were Ethiopian in origin. A randomized complete block design was used for the tests with three replications. The plot area was 14 m^2. Soil was ploughed at 35-40 cm depth during the 1st ten-days period of November 2012 and then harrowed in order to provide a good seedbed. Prior to sowing, 100 kg ha^{-1} of phosphorus fertilizer were applied. A total of 120 kg ha^{-1} of nitrogen fertilizer was applied, 50 kg ha^{-1} during sowing and 70 kg ha^{-1} prior to stem elongation. Sowing was carried out in the 2nd ten-days period of January both years using a total of 8 kg ha^{-1} of seed. Weeds control was carried out chemically using fluazifop-p-butyl 13:40 % at a rate of 1 L ha^{-1}. Dicotyledonous weeds were controlled manually using specific herbicides. Harvest was carried out in the 3rd ten-days period of June both years when the seed moisture content was about 9 %. Data on rainfall and temperature were collected from a meteorological station belonging to the Sicilian Agro-Meteorological Information Service situated close to the experimental site. The station was synchronized with GMT in order to operate using synoptic forecast models. It was equipped with a MTX datalogger and various sensors to provide data on the main meteorological parameters. In the two-year test period, the phenological stages of the species were observed: emergence, stem elongation, flowering, beginning of silique formation, end of silique formation and silique browning. Seed and crop residues yields were determined at the harvesting stage on a sample area of 7 m^2. On a sample of 5 plants, the plant height, number of siliques $plant^{-1}$, silique length, number of seeds $silique^{-1}$ and 1000-seed weight were recorded.

2.3 Energetic aspects

Crop residues were characterized both in physical and energetic terms by determining the moisture content (M), the ash content (A) and the gross calorific value (GCV). The moisture content was determined according to UNI EN 14774-2:2009 regulation, using a forced ventilation oven The ash content was determined according to UNI EN 14775 :2010 regulation. Dry samples were in fact placed in a muffle furnace. at 500 °C for approx. 2 hours, with a temperature gradient of 4 °C min^{-1}.The GCV for the ash-free dry matter was determined according to UNI EN 14918:2010 regulation, using Berthelot-Mahler bomb calorimeter. The agricultural residues were subsequently tested for pellet-making and the end product was subjected to a preliminary analysis of its physical and energy properties by determining ash content, GCV and mechanical durability (DU). The energy characterization of the pellet was determined according to the standard UNI EN-

14961-2 regulation. The pellets were obtained using shredded residues which were fed directly into the pellet machine. The residue was forced through a rotating die-hole press to form pellets which were then cut into 5-cm lengths. DU was determined using the Lignotester New Holmen Tester TekPro. This parameter is the difference, expressed as a percentage, between pellet weight before and after a cycle of stress which simulates, for example, transport. The mechanical durability was calculated using the following equation:

$$DU = \frac{MA}{ME} * 100 \quad (1)$$

where (MA) is the pellet weight after treatment and (ME) is the pellet weight before treatment. The ash content and GCV of the pellets were determined using the same methodology as for agricultural residues analysis.

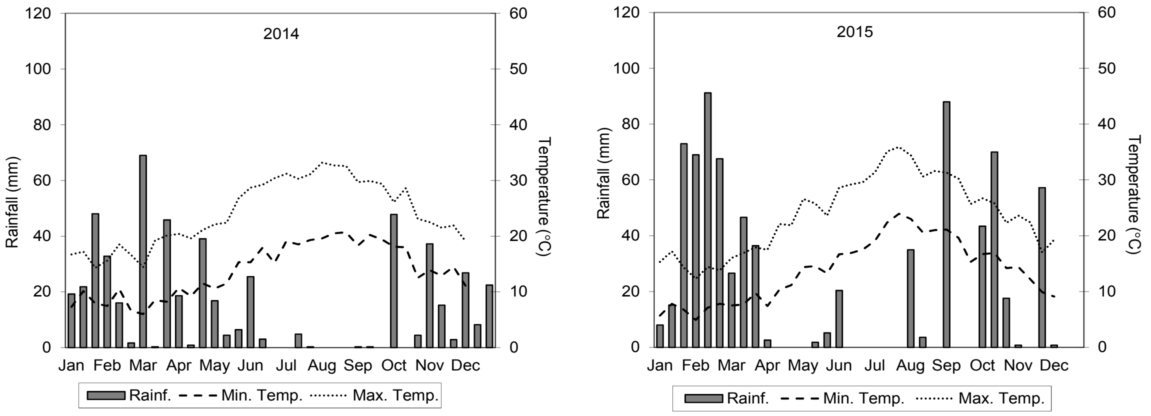
2.4 Statistical analysis

The statistical analysis was carried out by using the software SPSS for Windows. Data were submitted to the analysis of variance and the differences between means were further analysed with the Tukey test (P ≤ 0.01).

3. Results and discussion

3.1 Rainfall and temperature trends

In the study area, temperature trends were consistent with the ten-year average, with values never falling below zero. The total annual rainfall levels in the first and second years of tests were 539.1 and 780 mm respectively. The most significant rainfall events was 91 mm and it occurred during the 2nd 10-day period of February 2015. In the two-years testing, maximum temperature (35 °C) was recorded in the 2nd 10-day period 2015 while minimum temperature (5.7 °C) was determined in the 1st 10-day period of January 2015 (Figure 1).



(a) (b)

Figure 1: Rainfall and temperatures in 2014 and 2015.

3.2 Growing cycle

Length of growing cycle of all the accessions was found to be near to the field average of 136 days (Figure 2). Between the earliest (CN101698) and latest accession (CN101632) the difference was 14 days. Emergence occurred within 5 to 8 days, whilst stem elongation lasted an average of 57 days. Earliest flowering occurred in CN101686 (93 days) which reached 50% open-flower phase earlier than the field average of 96 days. Initial silique formation was affected by the staggered flowering of the species. In some accessions it took place when the open-flower stage had not yet reached 50%. Silique browning occurred between 9 and 21 days. All accessions indicated a good adaptation to the environment with a growing cycle ending before the 3rd 10-day period of June.

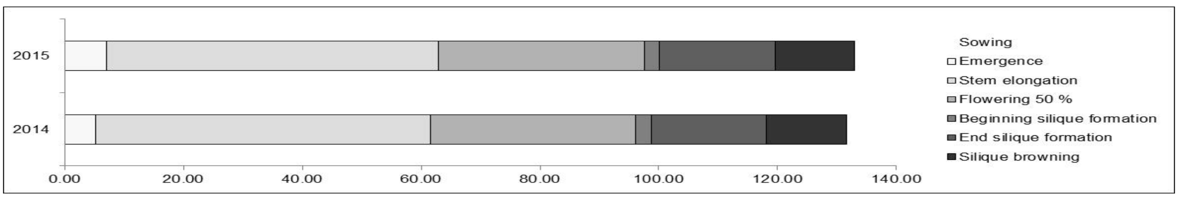


Figure 2: Length of growing cycle and main phenological stages of all accessions in the study. Two-year averages are shown.

3.3 Seed and crop residues yields

The main biometric and productive results are shown in Table 1.

Table 1: Effects of year and accession on main morphological and yield parameters of Brassica carinata. Average values of all accessions by year and of each accession for both years are reported.

	Plant height (cm)	Silique plant^{-1} (n)	Silique length (cm)	Seed silique(n)	Seed yield (t ha^{-1})	Residues yield (t ha^{-1})	1000-seed weight (g)
Year							
2014	152.31 A	425.10 A	4.31 A	16.22 A	2.65 A	7.63 A	2.41 A
2015	131.32.B	369.31 B	4.24 A	15.31 B	2.71 A	7.77 A	2.50 A
Accession							
CN101616	137.31 AB	267.42 CD	4.23 A	14.01 B	2.60 AB	5.20 C	2.42 A
CN101625	161.75 AB	253.22 CD	4.22 A	15.91 AB	2.61 AB	5.53 BC	2.53 A
CN101632	146.42 AB	315.73 C	4.25 A	13.92 B	2.32 B	6.62 BC	2.77 A
CN101633	137.51 AB	321.44 CD	4.29 A	15.73 AB	2.32 B	6.84 BC	2.76 A
CN101641	141.11 AB	514.34 AB	4.31 A	15.54 AB	2.70 AB	9.25 AB	2.66 A
CN101661	143.27 AB	294.46 CD	4.22 A	13.72 B	2.72 AB	8.67 AB	2.74 A
CN101662	135.12 AB	343.77 CD	4.25 A	13.91 B	2.64 AB	7.03 BC	2.33 A
CN101663	139.22 AB	288.73 C	4.35 A	15.11 AB	2.82 AB	7.25 BC	2.46 A
CN101664	120.33 B	415.84 BC	4.37 A	15.30 AB	2.33 B	6.57 BC	2.58 A
CN101665	164.21A	422.12 BC	4.27 A	17.66 A	2.84 AB	10.58 A	2.49 A
CN101666	165.89 A	232.24 D	4.31 A	17.94 A	2.82 AB	7.53 BC	2.61 A
CN101667	162.37 A	427.73 BC	4.36 A	16.73 AB	2.77 AB	10.73 A	2.44 A
CN101683	121.28 B	602.54 A	4.26 A	15.54 AB	2.26 B	7.34 BC	2.16 A
CN101684	139.78 AB	462.43 B	4.27 A	15.72 AB	2.28 B	8.77 AB	2.67 A
CN101685	133.34 AB	481.73 B	4.22 A	16.23 AB	2.54 AB	5.57 C	2.25 A
CN101686	169.35 A	575.44 AB	4.33 A	17.72 A	3.24 A	10.05 A	2.13 A
CN101687	131.28 AB	322.87 C	4.31 A	15.91 AB	2.86 AB	9.02 AB	2.46 A
CN101688	143.13 AB	410.23 BC	4.35 A	15.78 AB	2.79 AB	9.15 AB	2.68 A
CN101689	160.34 A	594.31 A	4.26 A	15.82 AB	2.96 AB	9.64 AB	2.58 A
CN101698	163.26 A	615.30 A	4.30 A	18.24 A	3.44 A	8.92 AB	2.43 A
Year x accession	**	**	**	**	n.s.	n.s.	**

Means followed by the same letter are not significantly different according to the Tukey test (P ≤ 0.05); **highly significant; n.s. significant

The “year” factor determined highly significant variations for most morphological parameters. No significant variations were found for the yield parameters. Comparing the two study years, the plants showed greater development in the first year. Lower rainfall levels in March/April of the 2nd year influenced plant growth, producing smaller plants (131.32 cm) with highly significant variations. With regards to the “accession” factor, variations were found to be highly significant for all the parameters in the study except for silique length and 1000-seed weight. Earliest accessions (CN101698, CN101686) showed the highest seed yield. The highest biomass yield was performed by CN101665 (10.58 t ha^{-1}). Crop residues yield on the average of the 20 accessions was 8.01 t ha^{-1}. The yield results of this research were compared with those of other studies and some differences were found. In a study carried out in three localities of Sicily, in similar climatic conditions, Copani et al. (2009) found average seed and residual biomass yield of 1.90 and 3.80 t ha^{-1} respectively. In Padua (Italy), Zanetti et al. (2009) determined the yield response of some varieties of *Brassica napus* and *Brassica carinata* under low and high production inputs and found an average seed yield of 2.90 t ha^{-1} for *Brassica carinata*. In three sites of Apulia region (Italy), Montemurro et al. (2016) compared different management practices of *Brassica carinata* in order to achieve optimum yield performance of the species and stated that the levels of biomass yield were influenced by the type of practices in the study. These researches highlight that the best level of yields in the cultivation of *Brassica carinata* depend on various factors among which genotype, environmental conditions and type of agronomic management play an important role.

3.4 Physical and energy results for crop residues

The “accession” factor determined significant variations for the M and A but no significant variations were found for the GCV (Table 2). Moisture content ranged from 16.62 % (CN101684) to 11.72 % (CN101662). The highest ash content value (8.01 %) was found in CN101662 whilst the lowest (5.79 %) in CN101687. Data were compared to reference values obtained by Duca et al.(2015) (Table 3).

Table 2: Effects of accession on main physical and energy parameters of crop residues and pellet.

	GCV (MJ kg^{-1})		Ash content (%)		Moisture content (%)	Mechanical durability (%)
	Residues	Pellet	Residues	Pellet	Residues	Pellet
CN101616	13.83 A	13.88 C	7.17 AB	6.71 AB	15.92 AB	74.01 AB
CN101625	13.73 A	16.67 AB	6.15 AB	6.24 B	15.44 AB	74.23 AB
CN101632	13.77 A	16.80 AB	7.15 AB	6.21 B	15.52 AB	74.22 AB
CN101633	14.23 A	17.15 AB	5.89 B	5.39 C	16.54 A	76.41 A
CN101641	14.02 A	16.85 AB	6.66 AB	7.82 AB	15.45 AB	72.90 AB
CN101661	13.56 A	16.45 B	6.81 AB	7.77 AB	14.99 AB	73.56 AB
CN101662	13.44 A	16.77 AB	8.01 A	8.14 A	11.72 B	74.99 AB
CN101663	13.22 A	16.82 AB	6.35 AB	7.51 AB	15.41 AB	75.03 AB
CN101664	13.77 A	16.87 AB	6.97 AB	6.36 B	16.55 A	75.23 AB
CN101665	14.15 A	17.34 A	7.02 AB	7.35 AB	14.98 AB	74.65 AB
CN101666	14.22 A	17.41 A	7.10 AB	7.37 AB	14.99 AB	74.72 AB
CN101667	14.02 A	16.86 AB	6.25 AB	6.99 AB	15.63 AB	76.27 A
CN101683	13.22 A	16.41 B	6.24 AB	6.75 AB	15.61 AB	74.55 AB
CN101684	13.37 A	16.45 AB	6.56 AB	6.15 B	16.62 A	72.11 B
CN101685	14.32 A	17.35 A	6.88 AB	8.22 A	12.11 B	74.33 AB
CN101686	13.61 A	16.82 AB	6.89 AB	8.25 A	11.79 B	72.14 B
CN101687	14.62 A	17.44 A	5.79 B	5.42 C	15.62 AB	76.12 A
CN101688	13.55 A	16.89 AB	6.54 AB	8.17 A	12.17 B	74.24 AB
CN101689	13.88 A	13.94 C	7.10 AB	6.34 B	16.61 A	74.99 AB
CN101698	13.56 A	16.15 AB	6.47 AB	6.74 AB	15.66 AB	74.66 AB

Means followed by the same letter are not significantly different according to the Tukey test ($P \leq 0.05$).

Table 3: Physical and energy characteristics of herbaceous crop species residues (Duca et al., 2015).

	GCV (MJ kg^{-1})	Ash content (%)	Moisture content (%)
Sunflower stalks	17.71	8.31	10.40
Rapeseed straw	17.78	7.51	9.12
Ethiopian mustard straw	18.53	5.50	7.90
Cardoon straw	17.84	8.11	8.30

The ash content values of *Brassica carinata* residues were found to be similar to reference values. But the GCV values were found lower than reference ones. However It is reasonable to assume that they are well suited to energy use and can represent an additional element of increasing income for farmers.

3.5 Physical and energy results for pellets

Variations regarding the “accession” factor were highly significant for all parameters examined (Table 2). CN101665, CN101666 and CN101685 were found to be of interest for GCV. The average value of the most valued accessions was 17.36 The ash content ranged from 8.25 (CN101686) to 5.39 % (CN101633), a difference of 2.86 %. The mechanical durability of the pellets ranged from 76.41 (CN101633) to 72.11 % (CN101684). CN101633 and CN101687 were found to have the best energy properties with a high GCV, low A and high DU for the pellets. In a study on wood pellet quality, Duca et al. (2014) reported general descriptive statistics on 130 pellet samples from forest residues. The authors determined average values of ash content (0.9 %), moisture content (6.7 %), net calorific value (17.0 MJ kg^{-1}) and mechanical durability (98 %) of the wood pellet. These values were compared with those of Ethiopian mustard pellet and they were clearly better in terms of pellet quality. Therefore it is possible to sustain that Ethiopian mustard pellet show low energy value and it is modestly suited to energy use compared to pellets made from forest residues.

4. Conclusions

Crop residues of Ethiopian mustard, such as straw, have generally an agronomic use with the technique of burial of residues. However the residual biomass deriving from the cultivation of this oilseed species can be used for combustion, for biogas production and in other processes with the consequent production of new biofuels. These residues are in fact a potential option for energy production, especially in the rural areas of the developing countries and could increase the income of farmers. In this study, the main physical and energy parameters of 20 different accession of Ethiopian mustard straw were analysed. They were found on average to be similar to other herbaceous crop species residues mainly for ash content but not for gross calorific value, probably due to a different number of samples being analysed. The Ethiopian mustard pellet made from crop residues was found modestly suited to energy use in terms of pellet quality compared with wood pellet. Despite the not high quality of Ethiopian mustard pellet, crop residues of *Brassica carinata* can be directly used as biofuel and/or for electricity and heat cogeneration due to their good energy characteristics. Then it is possible to sustain that they represent a valuable outputs of local agro-energy chains.

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