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Effects of Different Storage Techniques on Round-Baled Orchard-Pruning Residues

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Abstract: Baled pruning residue could be a valid solution to reduce the storage surface area in thermal and electrical power station. This study aimed to analyze the storage performance of pruning residues baled by a round baler considering three orchard tree species (apple, peach, and kiwi) and three different techniques (uncovered, under roof, and wrapped). The storage parameters considered were: moisture content, dry mass, and wood energy content of the material. The initial moisture content of the tree orchard specie (apple, peach, and kiwi) was different: lower for peach (41%) and higher for kiwi (51%). At the end of the storage period, all bales (covered and uncovered) obtained similar values to that of the air (about 20%); wrapped bales have highlighted no moisture content variation. The tested tree species showed a similar initial high heating value (18.70 MJ·kg^{-1}), but a different initial low heating value: lower for kiwi (7.96 MJ kg^{-1}) and higher for peach (10.09 MJ·kg^{-1}). No dry matter losses were observed in all test. Stored pruning residues in bales show good benefits in term of "biofuel" quality independent of the techniques adopted expect for the wrapping system that do not permit adequate drying of the biomass.

Keywords: prunings residues; round bales; storage benefits

1. Introduction

At present, bioenergy seems to be a valid solution to reduce environmental pollution, and for this reason its production in European countries is increasing [1]. Bioenergy can be produced by different renewable energy sources, but in this contest biomass highlights better results for electrical and thermal energy production on small and medium scales [2].

In this regard, agricultural residues can play an important role in energy production in all European countries [3,4], especially in Italy [5,6]. In fact, agricultural residues are a biomass source available every year with almost constant quantities and in areas accessible to agricultural convoys (tractor + trailer) and industrial vehicles (trucks) [7]. Moreover, the energy produced by agricultural waste shows also greater benefits in terms of environmental pollution compared to dedicated biomass plantations (short rotation coppices) [8]. Among all agricultural waste, pruning residues show higher potential energy production because their flue gas emissions are similar to those observed with woodchip [9], especially in southern Europe where orchards and vines are mainly sited [10,11]. Pruning residues, showing physical and chemical characteristics similar to other agricultural and forestry wood biomass, could be used as a biofuel for thermal and electrical energy production [9,12] In addition, the use of this biomass could offer benefits in terms of environmental pollution especially from energy and CO_2 emission points of view [8]. Orchards produce a significant amount of residues because they are pruned every year in order to increase the quality and quantity of fruit production [13].

At present, pruning residues are underused as an energy source and they become mulched into the fields or piled outside the orchard and, successively, burned [14]. These solutions can cause problems in different ways: time consumption, economic sustainability, and environmental pollution. Mulching, as well as maintaining the organic fraction, nutrients and the water content of the soil, can contribute to disease proliferation [4], while burning, besides being low cost [15], can produce several particulate emissions in the atmosphere [16].

In recent years, many studies have been performed on this topic, but the majority of these were mainly focused on machines used for harvesting residues [17,18], on harmful substances emitted during the combustion [19], and on biomass quantification [20]. Little research has been done on pruning residues storage that is a crucial operation in the overall biofuel supply chain because pruning residues are mainly produced in autumn and winter, while the power stations require biomass in all seasons [21]. In order to guarantee the biofuel during the whole year, it is necessary to store the biomass harvested: this could be done at the power station or in the farms [22]. During biomass storage, problems linked to dry matter losses and to the large surface required could occur [23].

In general terms, storing biomass pressed in bales can reduce the storage surface area or permit an increase in the amount of biofuel stored [24]. Furthermore, biomass in bales could highlight benefits also in transport operations. In fact, the biomass baled can be transported by all vehicles type with a load floor because bales can be piled also without the drop-sides. The biomass would be transported using specific "high-volume" trucks and agricultural trailers (drop-side height of 4 m), which requires specific equipment (agricultural telescopic loaders) to load them [25,26].

Besides these considerations, this study was aimed to analyse the storage performance of pruning residues baled by a round baler considering three orchard tree species (apple, peach, and kiwi) and three different storage techniques (uncovered, under roof, and wrapped).

2. Materials and Methods

The experimentation was performed in Cuneo, North-Western Italy, between mid-February 2017 and mid-September 2017. In Italy, these six months are the usual biomass storage period [27,28].

Storage dynamics were analysed using pruning residues produced by three orchard tree species: apple, peach, and kiwi. These orchard species are the most cultivated species in Cuneo area [29] and can be considered representative of the northwest of Italy [30]. All three orchards tested and the storage sites used in this study were in the same farm (44°34′60′′ N; 7°29′59′′ E). The diameter of all pruning residues ranged from 0.8 mm and 2.7 mm and the length varied between 260 mm and 782 mm.

Bales were made using a conventional agricultural round baler (Lerda rotocamer T135) with fixed baling chamber equipped with 6 rolls driven by a chain system modified for this purpose [31] (Figure 1). In detail, two rotor swathes were added at the pick-up (one of each side) and all mechanical elements were strengthened in order to facilitate the pruning residues' harvesting and baling. During the test, bales showed an external diameter of about 1.40 m and were packaged by a nylon wire. Six bales were made for each tree orchard species tested (apple, peace, and kiwi). In order to evaluate the efficiency on biomass conservation of the wrapping technique largely used in the agricultural sector for silage, others six bales with kiwi residues were made and wrapped using an agricultural wrapping machine (Supertino ABS 15T). The six bales were wrapped with six layers of plastic film.

Half of all bales made (three bales for each tree species and three wrapped) were placed on naked soil in open air, and the remaining 12 bales were stored under a roof. All bales were moved using a telescopic handler fitted with the specific crab device normally used in the agricultural sector for wrapped silage bales.

In order to determine the bulk density, each bale was weighted using a scale with an accuracy of 0.2 kg (Steinberg® SBS-KW-1TE). The storage dynamics of the biomass stored in bales were evaluated considering the moisture content and dry mass because these parameters influence directly the storage performance. In addition, during the test the temperature inside the bales was also monitored because its increase indicates a microbiological activity and consequently wood degradation [32]. These parameters (moisture content and temperature) were monitored for the entire storage period. The temperature measurements were performed by thermocouples (accuracy of 0.1 °C), while the moisture content of the biomass was monitored using specific probes coupled an electrical hygrometer (GANN®Hydromette HT85T) [28]. The probes were made with two short steel electrodes (20 mm) inserted in a chip of wood and linked to the hygrometric unit by wire. These probes have permitted the moisture content of the pruning residues to be monitored without moving and unwrapping the bales. The measurements performed by probes showed an accuracy of 1% in moisture content. All sensors (thermocouples and the moisture probes) were inserted in the middle of each bale. In order to record the temperature peaks typical of the first storage period, during the first month the sampling was performed daily. Thereafter, since it is known that moisture and temperature do change more gradually, the sampling frequency was reduced to one measurement each five days.

Figure 1. The agricultural round baler used to make bales.

Dry matter losses were calculated considering the dry mass of each bale before and after the storage. In this case, the water content of the biomass was determined by the gravimetric method following European standard UNI EN 14774-2 [33] because this method shows a better accuracy and reliability than the prototype probes adopted for the periodic monitoring [28].

Storage performance was analysed also under wood energy content point of view (low and high heating value). Specifically, high heating value (HHV) was determined following European Standard UNI EN 14,918 using an oxygen bomb calorimeter [34]. The formula used to calculate the low heating value (LHV) was [35]:

$$LHV = HHV(1 - M) - KM \tag{1}$$

where:

LHV = low heating value (MJ kg^{-1}),

HHV = high heating value (MJ kg^{-1})

M = moisture content of the pruning residues,

K = energy required to evaporate the water in wood (2.447 MJ kg^{-1}).

Since the weather conditions can affect the storage dynamics, air temperature (°C), air humidity (%), and rain precipitation (mm) were monitored by a weather station (DAVIS® Vantage Pro2) assembled near the storage site.

All data were processed using IBM-SPSS Advanced Statistic Package performing the analysis of variance (ANOVA) test considering a significance level of 0.05. Any significant difference between the treatments were checked with the Tukey post-hoc test because it resulted in being more appropriate with this data distribution [36,37].

3. Results

During the storage period, the ambient air temperature showed an average value of 16.1 °C. The minimum value of 1.4 °C was recorded at the beginning on the test, while the maximum value of 27.7 °C was observed at the end of the experimentation. The daily average air humidity varied between 41% and 100% with the lowest values recorded during the days without precipitation events. Moreover, a monthly average value of 80.1 mm and a total amount of 682.6 mm was observed for the rainfall (Figure 2). All meteorological parameters highlighted average values in line with those recorded in the last 10 years by the same weather station.

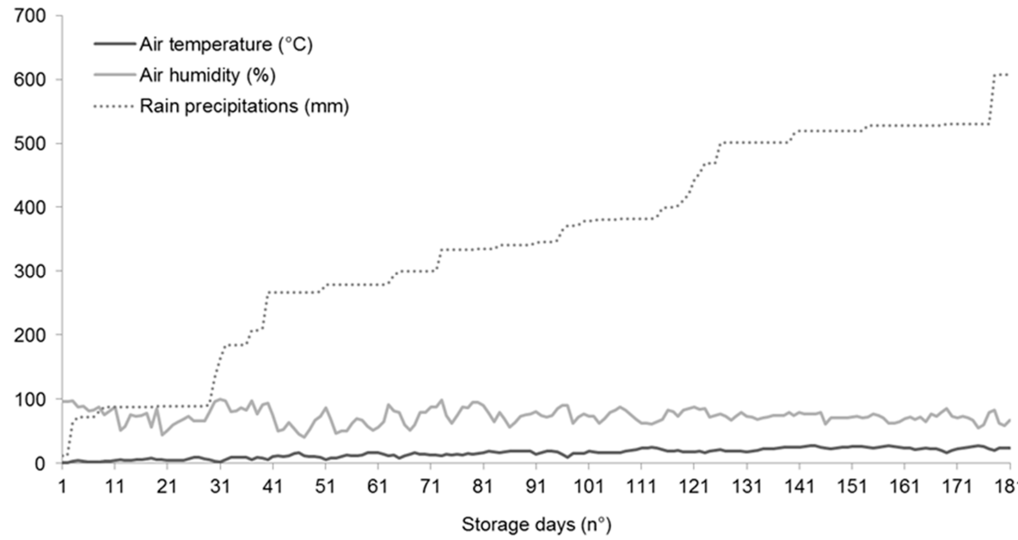

Figure 2. Values of air temperature, air humidity, and rain during the storage period.

The temperature values recorded within the bales are shown in Table 1. No temperature variation between values recorded inside of bales and those of ambient air temperature was found in all storage techniques and tree species during the whole storage period. The internal bale temperature varied from 1.5 °C (At the beginning of experimentation) and about 24 °C (at the end of the storage). The higher values observed at the end of the experimentation are attributable to the season (Summer). In addition, statistical analysis showed no significant difference between each treatment and the weather station (air) (Table 1).

The three tested orchard species showed different initial moisture contents: 51% for kiwi, approximately 45% for apple, and approximately 41% for peach. At the end of the storage period, independent of covered or uncovered the bales made of different tree species have obtained similar values (about 20%); no moisture content variation was observed in the wrapped bales. In all storage period the moisture content of the baled material was significant lower to air relative humidity (Table 2).

The tested tree species showed a similar initial HHV (average value of 18.70 MJ kg^{-1}), but a different initial LHV. The lowest value of LHV (7.96 MJ kg^{-1}) has been determined for kiwi, while the highest value (10.09 MJ kg^{-1}) was for peach (Table 3).

At the end of the storage period, significant differences were observed only in LHV values independently by storage techniques used (covered or uncovered bales). Nevertheless, it is important to underline that the wrapped prunings have not increase their LHV during the all storage period (Table 3).

Table 1. Temperature (°C) values recorded during the experimentation.

Bales Storage	Orchard Tree		Storage (Days)								
			1	**3**	**5**	**10**	**15**	**30**	**60**	**90**	**180**
	Air	mean	1.4a,a	5.3a,d	2.8a,b	4.5a,c	6.0a,e	2.8a,b	16.3a,f	14.4a,g	24.3a,h
Covered	Apple	mean	1.4a,a	4.9a,d	2.9a,b	4.7a,c	6.1a,e	3.2a,b	15.8a,f	14.5a,g	24.1a,h
		SD	*0.25*	*0.34*	*0.29*	*0.42*	*0.15*	*0.29*	*0.18*	*0.23*	*0.21*
	Peach	mean	1.6a,a	5.2a,d	3.1a,b	4.6a,c	6.4a,e	3.1a,b	16.5a,f	14.6a,g	23.9a,h
		SD	*0.43*	*0.32*	*0.31*	*0.28*	*0.21*	*0.43*	*0.35*	*0.29*	*0.34*
	Kiwi	mean	1.5a,a	5.0a,d	2.8a,b	4.5a,c	5.9a,e	2.8a,b	16.7a,f	14.1a,g	24.3a,h
		SD	*0.26*	*0.16*	*0.40*	*0.18*	*0.33*	*0.26*	*0.51*	*0.32*	*0.26*
	Kiwi (Wrapped)	mean	1.7a,a	5.2a,d	3.2a,b	4.6a,c	5.8a,e	3.3a,b	15.8a,f	13.9a,g	24.9a,h
		SD	*0.33*	*0.25*	*0.48*	*0.16*	*0.24*	*0.21*	*0.38*	*0.14*	*0.34*
Uncovered	Apple	mean	1.4a,a	5.1a,d	2.8a,b	4.5a,c	5.8a,e	3.0a,b	16.1a,f	14.1a,g	24.4a,h
		SD	*0.29*	*0.34*	*0.28*	*0.31*	*0.43*	*0.34*	*0.33*	*0.42*	*0.28*
	Peach	mean	1.3a,a	5.3a,d	2.9a,b	4.6a,c	5.8a,e	2.9a,b	15.9a,f	14.3a,g	23.8a,h
		SD	*0.45*	*0.19*	*0.35*	*0.42*	*0.23*	*0.38*	*0.19*	*0.31*	*0.27*
	Kiwi	mean	1.5a,a	4.9a,d	3.0a,b	4.4a,c	6.2a,e	2.9a,b	16.4a,f	14.1a,g	24.2a,h
		SD	*0.38*	*0.29*	*0.18*	*0.43*	*0.31*	*0.25*	*0.41*	*0.42*	*0.39*
	Kiwi (Wrapped)	mean	*1.6a,a*	5.3a,d	2.6a,b	*4.8a,c*	5.7a,e	3.2a,b	*16.8a,f*	*14.1a,g*	24.8a,h
		SD	*0.51*	*0.18*	*0.16*	*0.36*	*0.31*	*0.26*	*0.42*	*0.15*	*0.42*

Notes: *SD* = standard deviation; values reported in the table represent the average of three individual readings recorded in three different bales for each treatment; first letter evidences the eventual difference between treatment; second letter indicates eventual difference long all storage period.

Table 2. Moisture content (%) of the biomass stored.

Bales Storage	Orchard Tree		Storage (days)								
			1	**3**	**5**	**10**	**15**	**30**	**60**	**90**	**180**
	Air	mean	96d,f	88d,e	82e,d	88e,e	75e,c	100e,g	56c,a	81c,d	67c,b
Covered	Apple	mean	46b,d	46b,d	45b,d	43b,c	41c,c	39c,c	22a,b	18a,a	19a,a
		SD	*0.57*	*1.52*	*0.57*	*0.57*	*1.52*	*1.52*	*1.00*	*0.57*	*0.57*
	Peach	mean	42a,d	42a,d	41a,d	39a,d	36a,c	31a,c	21a,b	18a,a	18a,a
		SD	*1.52*	*1.52*	*0.57*	*0.57*	*0.57*	*1.00*	*0.57*	*0.57*	*0.57*
	Kiwi	mean	51c,f	50c,f	48c,e	46c,e	39b,d	34b,c	23a,b	19a,a	18a,a
		SD	*0.57*	*0.57*	*1.52*	*1.52*	*0.57*	*1.00*	*0.57*	*1.52*	*0.57*
	Kiwi (Wrapped)	mean	51c,a	51c,a	50d,a	51d,a	51d,a	50d,a	51b,a	51b,a	50b,a
		SD	*0.57*	*0.57*	*0.57*	*0.57*	*0.57*	*0.57*	*0*	*0.57*	*0.57*
Uncovered	Apple	mean	45b,d	46b,d	44b,d	43b,d	41b,c	44b,d	29a,b	22a,a	21a,a
		SD	*1.52*	*0.57*	*0.28*	*0.31*	*0.43*	*0.34*	*0.33*	*0.42*	*0.28*
	Peach	mean	41a,e	42a,e	42a,e	40a,e	37a,d	41a,e	27a,c	22a,a	20a,a
		SD	*1.00*	*1.52*	*0.35*	*0.42*	*0.23*	*0.38*	*0.19*	*0.31*	*0.27*
	Kiwi	mean	51c,e	51c,e	48a,d	49c,d	46c,c	48c,d	30a,b	22a,a	22a,a
		SD	*0.57*	*0.57*	*0.18*	*0.43*	*0.31*	*0.25*	*0.41*	*0.42*	*0.39*
	Kiwi (Wrapped)	mean	51c,a	52c,a	51d,a	51d,a	52d,a	51d,a	51b,a	51b,a	51b,a
		SD	*1.52*	*1.52*	*0.57*	*0*	*0.57*	*0.57*	*1.52*	*0.57*	*0.57*

Notes: *SD* = standard deviation; values reported in the table represent the average of three individual readings recorded in three different bales for each treatment; first letter evidences the eventual difference between treatment; second letter indicates eventual difference along all of the storage period.

The weight of bales is different as a function of the tree orchard specie (apple, peach, and kiwi) considered (Table 4). The lower weight resulted for the bales made with peach prunings residues (about 435 kg correspond to 260 kg m^{-3}), while the higher weight was observed in the bale of kiwi (about 485 kg correspond to 290 kg m^{-3}). No dry matter losses were observed in any treatment.

In this regard, it must be underlined that the wrapped bales, regardless to the storage method, at the end of storage period highlighted the presence of mold on the peripheral surface, suggesting an initial degradation of the material (Figure 3).

Table 3. High heating value (HHV) and low heating value (LHV) of bales.

Bales Storage	Orchard Tree		Initial Values (MJ kg^{-1})		Final Values (MJ kg^{-1})		Δ Value	
			HHV	LHV	HHV	LHV	HHV	LHV
Covered	Apple	mean	18.74a	8.94b	18.73a	14.85a	−0.01	5.91
		SD	*0.057*	*0.134*	*0.08*	*0.078*	-	-
	Peach	mean	18.66ab	9.94a	18.68ab	14.74a	0.02	4.80
		SD	*0.044*	*0.097*	*0.089*	*0.193*	-	-
	Kiwi	mean	18.68ab	7.96c	18.74a	14.78a	0.04	6.82
		SD	*0.067*	*0.139*	*0.095*	*0.163*	-	-
	Kiwi (wrapped)	mean	18.73a	8.00c	18.77a	8.02b	0.04	0.02
		SD	*0.075*	*0.156*	*0.055*	*0.147*	-	-
Uncovered	Apple	mean	18.73a	9.06b	18.73a	14.29a	0.00	5.23
		SD	*0.08*	*0.16*	*0.075*	*0.187*	-	-
	Peach	mean	18.68ab	10.09a	18.74a	14.36a	0.06	4.27
		SD	*0.089*	*0.174*	*0.095*	*0.162*	-	-
	Kiwi	mean	18.74a	7.86c	18.66ab	14.16a	−0.08	6.30
		SD	*0.095*	*0.167*	*0.044*	*0.088*	-	-
	Kiwi (wrapped)	mean	18.73a	7.86c	18.68ab	7.81b	−0.05	−0.05
		SD	*0.040*	*0.121*	*0.094*	*0.117*	-	-

Notes: *SD* = standard deviation; letters indicate significant difference between each treatment for α = 0.05.

Table 4. Fresh weight and dry matter values of the biomass stored.

Bales Storage	Orchard Tree	Fresh Matter (kg)			Total (*) Dry Matter (kg)	
		Bale		Total (*)	Beginning	End
		Mean	*SD*			
Covered	Apple	449.1b	7.00	1347.4	723.0ns	721.8ns
	Peach	431.1a	4.42	1293.2	758.7ns	754.8ns
	Kiwi	486.8c	6.81	1460.4	710.7ns	707.0ns
	Kiwi (Wrapped)	485.9c	6.94	1457.6	719.2ns	719.1ns
Uncovered	Apple	460.5b	8.66	1381.4	750.6ns	747.2ns
	Peach	437.5a	2.84	1312.6	778.8ns	775.6ns
	Kiwi	488.1c	3.40	1464.2	712.6ns	709.9ns
	Kiwi (Wrapped)	490.0c	7.69	1470.0	715.4ans	715.3ns

Notes: *SD* = standard deviation; (*) this value is referred to 3 bales; letters indicate significant difference between each treatment for α = 0.05; ns = not significant.

Figure 3. Degradation of the peripheral material in wrapped bales at the end of storage period.

4. Discussion

The initial moisture content of the different pruning residues tested result as similar to those found in other studies focused on the same tree orchard species [30].

In this study, the moisture content decrease with the same trend value both in covered and in uncovered bales. Also, if in the first approach this trend could be considered 'abnormal', this situation can be explained considering the climate conditions of the area where the current study was carried out. In fact, the climate of Italy, being drier, reduces the possibility of the remoistening of bales during rain events [38,39]. This situation is observable also in wood chips storage, where the results obtainable in southern Europe [23,24,27,40,41] are different than those observed in northern countries [42,43]. In addition, the good performance obtained by uncovered bales can also depend on the season during which the storage was performed (end of Spring and Summer) [44].

In the whole storage period, no significant differences between the temperature inside the bales stored with different techniques and air temperature were obtained showing an absence of microbiological activity and, consequently, an absence of dry matter losses [42]. This is a remarkable result because the pruning residues baled during the storage follow the normal trend of the wood piled [45] and not that of comminuted biomass [27,28].

The HHV values determined in this work were similar to those observed in forestry tree species used in dedicated crops for biomass production [45,46]. Since no differences between initial and final HHV values were observed for the different orchard tree stored with different method, it is possible that during the storage period no variations in wood energy content were obtained. Comparing these results to those obtained in forestry residue storage, this values trend is similar to that found in some experiments [47,48], but it is in contrast with other studies where the biodegradation caused an energy content loss after only 4 months [49,50].

Storing pruning residues in bales, independently from the storage techniques adopted (uncovered or covered), can be considered a valid solution because the 'biofuel' increased its LHV up to 185% in 6 months. These storage performances are similar to those found in logwood storage [45,47,51].

The wrapping system seems not to be an efficient storage technique because it did not permit an adequate drying of the pruning residues baled during the storage period and, at the same time, it encourages the material degradation. These results are in contrast with those obtained in another study [52] during the packaged woodchip storage where the material packaged maintained the same conditions up to two years. The cause of difference performances can be found in the different amount of air present in the bale packaged. In fact, the bale made with pruning residues show a lower density (290 kg m^{-3}) compared to a bale produced with woodchip (458 kg m^{-3}). The higher presence of air (oxygen) in the bale in combination with the water content on the material (fresh matter) encourage the proliferation rates in fungi and microbial community.

5. Conclusions

Stored prunings residues in pressed bales could be considered a valid solution not only in terms of transportation, but also in terms of storage performance. By adopting this method, the biomass dries during the storage period and does not highlight losses in terms of energy and dry matter content. These results are guaranteed regardless of the storage techniques used (covered and uncovered). In fact, the study highlights that in Mediterranean countries uncovered material shows similar performance to covered material (under a roof) in terms of dry matter losses and moisture content reduction. By contrast, the wrapping system can not be considered a good storage techniques for pruning residues because during the storage period it does not allow an adequate drying of the biomass and leads to some problems linked to the "biofuel" quality due to material degradation.

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