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Plant growth, yield, and fruit quality of tomato affected by biodegradable and non-degradable mulches

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Abstract: Research in southern Italy assessed the effects of biodegradable mulch on fruit yield and quality of two greenhouse tomato cultivars, 'Coronel F_1' and 'Kero F_1'. Three mulching types (two MaterBi biodegradable black films, MB N2/12 amnd MB N8; black polyethylene film, low-density polyethylene (LDPE)) and not mulched control were compared. 'Coronel F_1' showed higher values of fruit yield, total crop biomass and leaf area index (LAI). MB N8 and LDPE films led to the highest fruit yield and growth indexes, whereas not mulched control to the lowest. Fruit dry residue and soluble solids were highest under MB N2/12 and MB N8, titratable acidity was highest under MB N8. Fruits grown under MB N8 and LDPE mulches attained the highest levels of colour components "*L*" and "*b*" respectively, and MB N8 the highest fruit firmness. MB N2/12 and MB N8 showed the highest levels of antioxidants and antioxidant activity. Biodegradable polymers improved root growth conditions and fruit quality, showing suitable features for sustainable vegetable production.

Keywords: *Solanum lycopersicum* L.; biodegradable films; production; antioxidants; waste valorisation

Tomato (*Solanum lycopersicum* L.) is cultivated in many areas of Asia (China, India, Turkey, Iran), Africa (Nigeria, Egypt), United States, and Europe (Italy, Spain). The surface area in tomato accounts for 5,023,810 ha worldwide (FAOSTAT 2014).

The fruits of this species are rich in antioxidants, whose role is essential as protective screens against ultraviolet radiation (Jansen et al. 2001), though their excessive accumulation can potentially damage lipids, proteins and nucleic acids (Cho, Kleeberger 2010). Tomato is one of the vegetable crops benefiting from soil mulch in the last decades (Ngouajio et al. 2008), and the mulched area is still increasing worldwide (APE 2013). Notably, just 3.6% of the mulch films currently used are biodegradable, with the rest represented by plastic materials, usually polyethylene, which has raised critical disposal issues. Indeed, plastic degradation is a multifaceted complex process which is strongly influenced by the nature of the plastics itself as well as by biotic and abiotic conditions they are exposed to, and it results in a significant environmental impact (Kasirajan, Ngouajio 2012). Currently, biodegradable polymers represent an alternative to traditional non-biodegradable materials, whose recycling is often impractical or not economically sustainable. Mater-Bi is a starch-based biopolymer that combines characteristics of the traditional plastics with a biodegradation rate similar to that of the cellulose film (Bastioli et al. 1990). Mater-Bi black mulch was shown to be a good alternative to polyethylene in organic production under the Mediterranean continental climate (Martín-Closas et al. 2008).

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Prior to the cost evaluation of these materials at farm scale, taking into account the expense saving due to their soil incorporation in place of removal and disposal, the effects of biodegradable mulches need to be scientifically investigated, with reference to tomato fruit yield as well as on quality of both fruit and residual biomass for energy production potential. In this respect, research was carried out in southern Italy with the aim to compare different biodegradable mulches with the conventional low-density polyethylene (LDPE), in interaction with two tomato cultivars.

MATERIAL AND METHODS

In 2014 and 2015 research on tomato in greenhouse was carried out in S. Agata dei Goti (Benevento, southern Italy) on a clay-sandy soil. The trend of temperatures is shown in Fig. 1. Comparisons were made of two similar-type tomato cultivars ('Coronel F_1' and 'Kero F_1') in factorial combination with three mulching types (two MaterBi biodegradable black films, MB N2/12 and MB N8, having 15 and 12 μm thickness respectively, and made of corn starch by Novamont S.p.A. (www.novamont.com); a black polyethylene film, LDPE, 50 μm thick) and not mulched control, using a split plot design with three replicates. The elementary plot had a 20 m^2 surface area.

Prior to tomato planting on May 9 at 2.5 plants per m^2, the soil was fertilized with 50 kg/ha N, 60 P_2O_5, 70 K_2O, and the mulch films included in the experimental protocol were applied. During the cultivation, the following practices were done: delivery of 100 kg/ha N and 150 kg/ha K_2O; drip irrigations; hoeing; plant protection against fungal diseases and insects were practised in compliance with the regional regulation. The maximum leaf area was assessed on random plant samples, using a bench top LI-COR leaf area meter. Harvests of ripe fruits were performed from July 27 to August 8. Every time, in each plot, the weight and number of ripe undamaged fruits classified as marketable were determined, as well as of fruit mean weight on 30 unit samples. Harvest index was calculated as a ratio between marketable fruits and total plant biomass and it was expressed as a percentage. At the second harvest, fruit samples were taken from each plot and immediately transferred to laboratory in order to make the following quality determinations: dry residue, through dehydration of the fresh samples in an oven at 70°C until they reached constant weight; soluble solids expressed in °Brix by digital refractometer; pH by digital pH meter; fruit surface colour on two diametrically opposed points by a reflectance colorimeter Minolta CR-200 using the space of CIELab ($L^*a^*b^*$); flesh firmness by digital penetrometer with a 8 mm tip (T.R. Turoni s.r.l., Forli, Italy). Total polyphenol, flavonoid and carotenoid content, ascorbic acid, and antioxidant activity were assessed as follows. Total polyphenol content was assessed as previously described (Caruso et al. 2014). Total flavonoid content was determined by the colorimetric method proposed by Zhishen et al. (1999). Total carotenoid content was assessed

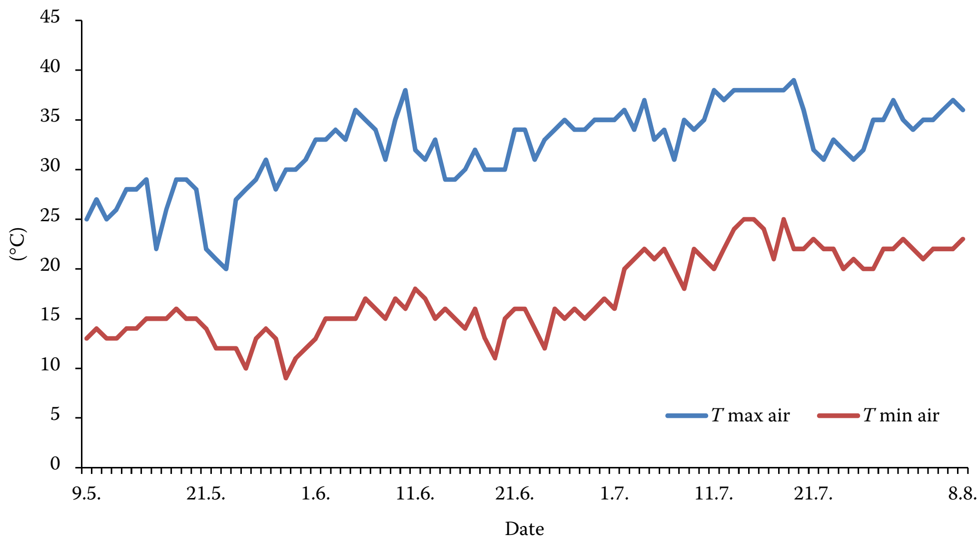

Fig. 1. Trend of air temperature in S. Agata dei Goti (Benevento, southern Italy) as an average of 2014 and 2015

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upon a methanolic extraction (100%; 1 : 4 w/v) and then assessing the extract absorbances at 470, 653 and 666 nm, using Wellburn equations (1994).

Ascorbic acid was determined by Mallik and Singh method (2005). Total antioxidant activity was measured by the 1,1-diphenyl-2-picryl-hydrazil (DPPH) test, following the method of Brand-Williams et al. (1995) with some modifications. The values obtained were interpolated with those from a calibration line built up using Trolox as a reference antioxidant and the results were expressed as µmol trolox equivalents/g fresh weight.

At the end of crop cycles, assessment of aboveground residual biomass was performed and samples randomly taken from each plot were transferred to the laboratory, where they were dried, milled to final material composed of particles ≤ 1 mm diameter, and stored in air-tight bags at –20°C. Determinations of lignin, cellulose, hemicellulose and pectin were performed using the analytical procedures reported by Ercolano et al. (2015).

Data were processed by two-way analysis of variance and mean separations were performed through the Duncan multiple range test, with reference to 0.05 probability level, using SPSS software version 21. Data expressed as percentage were subjected to angular transformation prior to processing. The variables examined in our research were not significantly affected by the research year and, therefore, only mean data of the two years are reported. Moreover, no significant interactions arose between the two experimental factors 'cultivar' and 'mulching type' and for this reason only the data relevant to their main effects are showed.

RESULTS AND DISCUSSION

Yield and growth

The time span from tomato planting to the first harvest was 81.5 days on average. Tomato earliness and yield parameters resulting from the comparison between the cultivars and the mulching types tested are shown in Table 1. No significant differences were recorded in fruit ripeness precocity between the examined hybrids. Compared to cv. 'Kero F_1', cv. 'Coronel F_1' had a 14.8 % higher fruit yield, due to higher fruit number (+ 16.4%), whereas mean weight was not affected by cultivar (Table 1). Irrespective of productive results, the plants showed an advantage of fruit biomass to shoot and leaf biomass (Table 2), which was not affected by cultivar (76.2% as an average). Corresponding to yield, cv. 'Coronel F_1' had higher values of total and residual crop biomass, +18 and +20, respectively, as well as leaf area index, +14.3, compared to cv. 'Kero F_1' (Table 2).

The comparison between mulching treatments (Table 1) shows that LDPE resulted in higher harvest precocity than not mulched control (79 vs 84 days after planting, respectively), in agreement with the reports of Ibarra et al. (2008), who found a positive correlation between the crop earliness and soil heat accumulation under mulched treatments. However, no significant differences were detected between the plastic and biodegradable mulches. Moreover, MB N8 and LDPE had the highest fruit yield, 77.8 t/ha on average, due to the highest fruit number and mean weight; the not mulched control had the worst performance, 68.8 t/ha.

Table 1. Tomato precocity and yield as affected by cultivar and mulching type

	Harvest beginning (days from transplant)	Marketable fruits		
		weight (t/ha)	number (per plant)	mean weight (g)
Cultivar				
Coronel F_1	81	79.3	33.4	74.1
Kero F_1	82	69.1	28.7	75.3
	ns	*	*	ns
Mulching type				
MB N2/12	82^{ab}	72.7^{b}	30.8^{ab}	73.9^{b}
MB N8	81^{ab}	77.6^{a}	31.7^{a}	76.7^{a}
LDPE	79^{b}	78.0^{a}	32.0^{a}	76.2^{a}
Not mulched control	84^{a}	68.8^{c}	29.7^{b}	72.4^{b}

ns – no statistically significant difference, *significant difference at $P \leq 0.05$; within each column, means followed by different letters are significantly different according to the Duncan test at $P \leq 0.05$

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Table 2. Tomato growth as affected by cultivar and mulching type

	Harvest index (%)	Total biomass (t/ha d.w.)	Residual biomass (t/ha d.w.)	LAI (m^2/m^2)
Cultivar				
Coronel F_1	75.8	9.0	4.2	3.2
Kero F_1	76.6	7.6	3.5	2.8
	ns	*	*	*
Mulching type				
MB N2/12	76.6^{ab}	8.0^{b}	3.6^{b}	3.1^{a}
MB N8	77.1^{a}	8.6^{a}	3.9^{a}	3.0^{a}
LDPE	76.2^{ab}	8.7^{a}	4.0^{a}	3.1^{a}
Not mulched control	74.0^{b}	8.1^{b}	4.0^{a}	2.7^{b}

ns – no statistically significant difference; *significant difference at $P \leq 0.05$; within each column; means followed by different letters are significantly different according to the Duncan test at $P \leq 0.05$; LAI – leaf area index

In our research, LDPE and MB N8 biodegradable mulch (50 and 15 μm thick respectively) gave the best yield results, not differentiating from each other, which suggests that this type of biodegradable mulch is a good alternative to plastic in terms of fruit production. Moreover, MB N2/12 (12 μm) also encouraged the production compared to bare soil, which highlights the importance of both increasing soil temperature and controlling weeds without costly manual intervention (Cirujeda et al. 2012). As shown in Fig. 2, both the maximum and minimum soil temperatures were highest under LDPE, in agreement with previous studies (Moreno et al. 2016). The lowest temperatures were in the not mulched control; MB N2/12 showed lower values of soil temperature than LDPE and MB N8. In all treatments the mean values of soil root-zone temperature fell in the 20–30°C range, fitting tomato requirements (Tindall et al. 1990) and thus enhancing physiological processes, such as uptake of water and mineral nutrients, as well as growth and yield which are best affected by 25–26°C (Díaz-Pérez, Batal 2002). However, the maximum soil temperature under LDPE exceeded 30°C for an average of 8 days in July, and this overheating may have damaged the crop (Schonbeck, Evanylo 1998).

The differences in soil temperatures among different mulch types could be attributable to their composition (Moreno, Moreno 2008). Notably, the highest soil temperatures reached under LDPE may result from the optical properties of this material, which reflects or transmits less than 10% of solar radiation and absorbs the remaining over 90% fraction (Ham et al. 1993). Indeed, if there is good contact between soil and mulch, significant heat conduction can occur, thus increasing soil temperature during the daytime (Teasdale, Abdul-Baki 1995). MB N8 biodegradable mulch resulted on average in 1.3°C lower mean temperature than under LDPE, due to its higher permeability which encourages gas exchange with the open air (Chandra, Rustgi 1998; Moreno, Moreno 2008). The lowest bare soil temperature is the result of the highest heat loss upon reflectance and evaporation (Teasdale, Abdul-Baki 1995). The highest minimal soil temperatures recorded under LDPE may be explained by the more effective heat accumulation of this material during the day, though the energy loss overnight was higher than the biodegradable mulches as witnessed by the more amplified day-night temperature difference (Ham et al. 1993; Teasdale, Abdul-Baki 1995).

All mulch types reduced the soil temperature fluctuation as compared to bare soil, as also described by Moreno et al. (2016).

The mulching type did not show a significant effect on harvest index, whereas the best yielding treatments also resulted in the highest production of total biomass. LDPE, MB N8 and not mulched control led to the highest residual biomass accumulation whereas leaf area index was lowest under the not mulched control (Table 2).

Fruit quality and antioxidants

As reported in Table 3, no significant differences arose between the two cultivars in relation to fruit quality parameters. As for the comparison among the mulching types, dry residue and soluble solids

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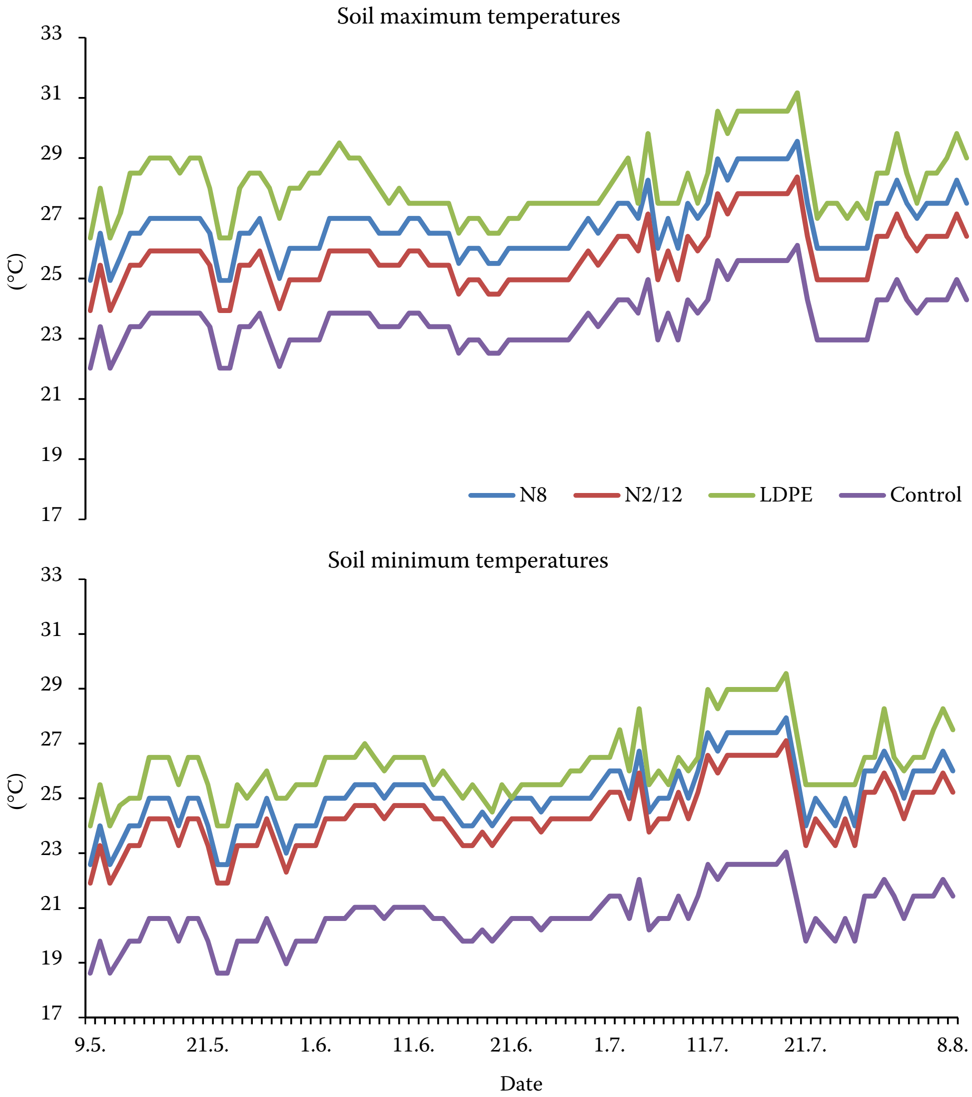

Fig. 2. Trend of soil temperature in tomato under different mulching types, as an average of 2014 and 2015

were highest under MB N2/12 and MB N8 treatments and lowest in the fruits harvested in LDPE mulched plots and in the control. The titratable acidity was highest with MB N8 mulch and lowest in the control, similarly to the colour component "*a*", whereas the opposite effect was recorded for pH. Mulching with MB N2/12 resulted in lowest values of "*L*" and "*b*" fruit colour components, whereas in plots with MB N8 and LDPE the fruits attained the highest levels of "*L*" and "*b*". MB N8 led to the highest fruit firmness and LDPE and not mulched control to the lowest.

As for antioxidants (Table 4), the fruits from plots with MB N2/12 and N8 showed the highest concentrations of both the antioxidants analysed and the antioxidant activity. LDPE and the not mulched soil resulted in the lowest values of polyphenols, flavonoids and ascorbic acid, whereas LDPE had the lowest carotenoids and the control the lowest antioxidant activity.

The antioxidants content reportedly show a positive correlation with the antioxidant activity (Chaieb et al. 2011). During thermal stress the accumulation of phenols, and thus the increase in the ability to biosynthesis, was stated by Rivero at al. (2001). In tomato this phenomenon occurred at too high temperature, and in watermelon at too low temperature. Phenylalanine ammonium-lyase (PAL) is considered the main enzyme in the phenyl-propanoid building pathway, catalyzing the L-phenylalanine turning into trans-cinamic acid, which is the intermediate compound in phenolic biosynthesis (Dixon, Paiva 1995). This enzyme activity increases in response to thermal stress and it is considered one of the main cell acclimation

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Table 3. Tomato fruit quality indicators as affected by cultivar and mulching type

	DR (%)	SSC (°Brix)	TA (% d.w.)	pH	Colour "*L*"	Colour "*a*"	Colour "*b*"	Firmness (kg/cm)
Cultivar								
Coronel F_1	6.4	5.6	7.1	4.2	39.7	30.2	19.6	0.72
Kero F_1	6.2	5.3	6.9	4.3	41.4	30.4	22.5	0.72
	ns	ns	ns	ns	ns	ns	*	ns
Mulching type								
MB N2/12	6.6[a]	5.7[a]	6.8[b]	4.3[ab]	39.6[b]	30.8[ab]	18.7[c]	0.74[b]
MB N8	6.5[a]	5.7[a]	7.3[a]	4.2[b]	42.6[a]	32.7[a]	20.7[bc]	0.79[a]
LDPE	6.0[b]	5.2[b]	7.0[ab]	4.3[ab]	40.8[ab]	29.2[bc]	23.5[a]	0.69[c]
Not mulched control	5.8[b]	5.1[b]	6.4[c]	4.5[a]	40.7[ab]	27.1[c]	21.9[ab]	0.71[bc]

DR – dry residue; SSC – soluble solids content; TA – titratable acidity; ns – no statistically significant difference; *significant difference at $P \leq 0.05$; within each column, means followed by different letters are significantly different according to the Duncan test at $P \leq 0.05$.

Table 4. Tomato fruit antioxidant content (per g dry residue) and activity as affected by cultivar and mulching type

	Polyphenols (mg gallic acid equivalents)	Flavonoids (mg catechin equivalents)	Ascorbic acid (mg)	Carotenoids (mg)	Antioxidant activity (mmol TE)
Cultivar					
Coronel F_1	39.4	0.80	2.44	1.92	49.6
Kero F_1	39.2	0.81	2.49	2.05	49.4
	ns	ns	ns	ns	ns
Mulching type					
MB N2/12	46.1[a]	0.76[a]	2.43[a]	2.25[a]	60.0[a]
MB N8	43.0[a]	0.79[a]	2.44[a]	2.30[a]	61.4[a]
LDPE	28.8[b]	0.72[b]	2.21[b]	1.64[c]	38.8[b]
Not mulched control	29.0[b]	0.74[b]	2.14[b]	2.05[b]	26.5[c]

ns – no statistically significant difference, *significant difference at $P \leq 0.05$; within each column, means followed by different letters are significantly different according to the Duncan test at $P \leq 0.05$

symptoms against stress (Leyva et al. 1995). On the other hand, phenol oxidation is performed either by peroxidases (POD) or priority by polyphenols oxidases (PPO); the latter enzyme catalyses the oxidation of o-diphenols to o-diquinons, as well as monophenols hydroxylation (Martínez-Téllez, Lafuente 1997). Both enzymes have been associated with physiological damage caused by thermal stress and, in fact, under high or low temperature stress these enzymes are activated, whereas the enzymes oxidizing the same compounds are inhibited (Leyva et al. 1995; Martínez-Téllez, Lafuente 1997). Accordingly, soluble phenolic compounds can accumulate as a mechanism of acclimation to overcome high or low temperature stress (Rivero et al. 2001). Moreover, polyphenols play the important role of preventing enzymatic degradation of ascorbic acid (Altunkaya, Gökmen 2009), the latter having a vital role in plants, as a redox buffer, as a strong antioxidant, and as a regulator of photosynthesis enzymes, phytohormones, cell division and growth (Barth et al. 2006).

Cell wall chemical composition of crop residual biomass

As shown in Table 5, cv. 'Coronel F_1' attained higher contents of lignin, hemicellulose and pectin, but lower cellulose percentage in the cell wall of residual biomass compared to cv. 'Kero F_1'. Interestingly, no fruit quality indicators showed differences between the two cultivars, except for colour "*b*" component, whereas the cell wall composition of the residual biomass, mostly made of stalks and leaves, was significantly affected by genotype. Similar values of crop waste composition in tomato cultivar 'Kero F_1' were detected in previous research (Ercolano et al. 2005).

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Table 5. Chemical composition of tomato residual biomass as affected by cultivar and mulching type

	Lignin	Cellulose	Hemicellulose	Pectin
	(% of dry weight)			
Cultivar				
Coronel F_1	20.3	47.1	14.7	6.6
Kero F_1	18.3	51.9	13.4	4.3
	*	*	*	*
Mulching type				
N2/12	18.5^b	50.6^a	13.7^b	5.2^b
N8	18.4^b	50.9^a	13.7^b	5.1^b
LDPE	18.9^b	51.1^a	13.3^b	4.9^b
Not mulched control	21.5^a	44.8^b	15.6^a	6.9^a

ns – no statistically significant difference, *significant difference at $P \leq 0.05$; within each; column, means followed by different letters are significantly different according to the Duncan test at $P \leq 0.05$

As regards the mulching types (Table 5), no significant differences were recorded between the treatments, whereas the control showed the highest values of lignin, hemicellulose and pectin but the lowest cellulose percentage. Therefore, it may be inferred that the lower soil temperature associated with tomato growing in bare soil resulted in lower cellulose synthesis, which is essential for energy production potential. The residual biomass composition is the indicator of its energy production potential and, in our research, glucose from cellulose gave the major contribution, taking into account that the percentage of hexoses and pentoses deriving from hemicellulose is much lower. In this respect, targeting biofuel production, cv. 'Coronel F_1' had better performance than cv. 'Kero F_1' in terms of theoretical ethanol yield, 347 vs 291 l/ha, respectively. LDPE and MB N8 resulted in the same highest value, 340 l/ha on average. This theoretical yield was calculated from the conversion of glucose contained in cellulose (Dowe, Mcmillan 2008), which should represent the 70–75% occurrence on the total production, the remaining contribution coming from hemicellulose monosaccharides (Ercolano et al. 2015). However, the higher ethanol production recorded for the cv. 'Coronel F_1' was dependent on its higher residual biomass amount, the latter showing a better quality in cv. 'Kero F_1' crop waste.

CONCLUSION

Research was carried out in southern Italy on two tomato genotypes in order to evaluate replacing conventional polyethylene mulch with biodegradable material made of corn starch. The latter was more effective than the plastic mulch in terms of fruit yield and quality as well as on the potential of crop residual biomass to be converted into biofuel. Indeed, the biodegradable mulch led to soil temperature increase, but never over the optimal range, which occurred in some days under the plastic mulch. Unlike polyethylene, biodegradable mulch had neither an adverse environmental impact nor it needed hand labour for removal from soil.

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