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Experimental Study to Support Local Sunflower Oil Chains: Production of Cold Pressed Oil in Central Italy

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Abstract: Sunflower is one of the most important oilseed crops cultivated in the world for different purposes. In Italy, the production is mostly located in the central area, representing 70% of Italian production. The market demand for sunflower oil is higher than the national production. There is an increasing request for cold pressed sunflower oil for food application. The success of this activity is linked to a correct setting up and management of the production and supply chain with a valorization of products and by-products. To this aim, information is needed, and this paper is focused on the cultivation of sunflower in central Italy using suitable hybrids, as well as on the study of the cold extraction performance of the sunflower seed produced and the quality of by-products and residues. Results indicate that, on average, a range of about 1.0–1.5 t ha^{-1} of cold pressed oil and different amounts of by-products can be obtained. According to a proposed scenario, 30 ha cultivated with sunflower are needed to create a complete supply chain within the farm, avoiding many additional passages and maintaining all the value for the farmer. It is important to use suitable hybrids for obtaining good yield, but also the cold extraction performances are important because they also affect the quality of by-products and residues that can be valorized themselves to improve sustainability.

Keywords: mechanical extraction; sunflower cultivation; traceability; sustainability

1. Introduction

Sunflower is one of the most important oilseed crops in the world, cultivated in developed and developing countries. The motivation lies in its tolerance to drought and to different soil typologies [1]. Sunflower vegetable oil can be used for food, but also as feedstock for biodiesel production, although this latter use is less profitable today, especially in some countries.

In Italy, sunflower is cultivated mainly for food purposes. The most important area for production is central Italy, with a sunflower seed production in 2018 of over 150.000 tons (standard moisture content 9%) and 72,600 ha cultivated (ISTAT, 2018), representing about 70% of Italian production in 2018. The market demand for sunflower oil is higher than the production, and a significant amount of sunflower oil is imported in Italy. In this context, in recent years, there is an increase in the use of sunflower oil in substitution of palm oil as food feedstock, and an increase in the production of cold pressed sunflower oil, especially by small operators like farmers becoming oil producers. It is due to the raising interest of consumers in the use of this product for health and environmental reasons.

The success of cold pressed sunflower oil production is obviously linked to a correct setting up and management of the value chain with a valorization of the main product and by-products also in terms of biofuels and biomaterials. To this aim, a lot of information is needed. The choice of the best sunflower hybrids for the specific location is important, because it affects seed yield and oil yield due to different rainfall, temperature, and soil conditions. Knowledge of the extraction step is important, in order to maximize oil quantity and quality. It is also important to study the physical-chemical properties of residues and by-products that can be valorized in different ways to increase the overall profitability and sustainability.

The study of the best sunflower hybrids has been studied in the last decades in Italy by the CREA-CIN [2]. On sunflower oil quality, there are many papers dealing with different aspects such as analysis of physicochemical properties [3], effects of the contents of impurities and seed hulls in cold pressed oil [4], effect of storage time [5], polyphenol content [6], and methods to maintain the quality during storage, e.g., by flushing with nitrogen [7].

In addition to the sunflower oil quality, the knowledge of by-products, mainly sunflower press cake, hulls, and cultivation residues is important. Duca et al. [8] evaluated the quality of straw, hulls, and press cakes from sunflower oil production chain, assessing their energetic potential and suggesting possible applications. Other authors studied the possibility to produce protein isolates from sunflower press cake for food applications [9], while other researchers tested the utilization of the fine particles obtained from the filtration of cold pressed vegetable oils for use as cosmetic or food ingredient [10].

Unfortunately, it is difficult to find works dealing with experimental results of sunflower cultivation and vegetable oil extraction together for a specific region. To fill this gap, the present paper is focused on the cultivation of sunflower in central Italy using suitable hybrids, as well as on the study of the cold extraction performances of the sunflower seed produced and the quality of by-products and residues. This provides also a mass balance of the production, and can represent a good support for small agricultural companies producing sunflower oil for food or are interested in this production with a particular attention to sustainability and traceability aspects. To this aim, a specific scenario has been defined, considering the results of the present study and the work carried out by other authors.

2. Materials and Methods

The production of cold pressed sunflower oil in central Italy entails the following steps: Sunflower cultivation; transportation of sunflower seed by truck, generally over short distances; cold extraction in small enterprises by means of screw press; decantation and/or filtration by filter-press.

To get useful information on the production chain of cold pressed sunflower oil, different tests regarding the two key steps of sunflower cultivation and sunflower extraction were carried out. The sunflower seed production was studied in different locations of central Italy, as detailed below. The cold pressing of sunflower seed has been tested in the Biomasslab of the Department of Agricultural, Food and Environmental Sciences (D3A) of Università Politecnica delle Marche, as detailed below.

2.1. *Sunflower Seed Production*

To evaluate the performance of sunflower cultivation in central Italy, specific experimental tests were carried out, taking into account the most representative commercial sunflower hybrids. Locations, cultivation years, inputs, and analysis carried out on sunflower plants and seeds are detailed as follows.

2.1.1. Locations

The agronomic tests were performed by the following institutes: Council for Agricultural Research and Economics—Research Centre for Industrial Crops (CREA-CIN), in Osimo (AN), located in Marche region; Tuscan Regional Lands, in Marciano della Chiana (AR), in Tuscany Region; 3A-Umbria Agrifood Technology Park (3A-PTA), located in Umbria region. These operational units worked in their experimental farms placed respectively in Osimo (Lat. 43°29′07″ N—Long. 13°28′55″ E); Monteleone di Fermo (Lat. 43°2′55″ N—Long. 13°31′49″ E); Cesa (Lat. 40°57′46″ N—Long. 14°13′50″ E); Papiano (Lat. 42°54′24″ N—Long. 12°20′12″ E).

The physical-chemical characteristics of soils in the four locations of central Italy are similar. In more details, soil texture is loam in Papiano, and clay-loam in the other locations. The soil organic matter varies between 19.2 (Osimo) and 24.0 g kg^{-1} (Papiano), while the nitrogen content between 1.17 and 1.4 g kg^{-1}. pH results moderately alkaline (7.6–8.1) in all the locations. Soils showed low levels of available phosphorus (21–36 mg kg^{-1}), but good levels of available potassium (151–209 mg kg^{-1}) especially in Tuscany and Marche regions. Soil characteristics are therefore suited for a standard sunflower cultivation in Italy. To better understand the results, the poliannual thermo-pluviometric trends and the 2015–2017 trends were analyzed and compared.

2.1.2. Cultivation Years

During the 2015–2017 period, four sunflower hybrids were tested: Mas 86.OL and SY Excellio (high oleic); Mas 85.SU and NK Stradi (high linoleic). A randomized bloc experimental design was adopted, with three repetitions and 15 m^2 parcels which had a harvestable surface area at least of 10 m^2. The distance between the files was 0.65 m in Cesa, and 0.50 m in the remaining locations, according to local customs. The sowing was performed in the first half of April, mechanically and in continuous row to obtain a real investment of 6 plants/m^2 after manual thinning (when the crop reached 2–4 real leaves).

2.1.3. Inputs

The fertilization was performed distributing 100 kg ha^{-1} of ureic nitrogen: 60% during sowing and 40% at the thinning stage. Chemical weed control was performed on the crop using a mix of pendimetalin + aclonifen (Stomp + Challenge) in pre-emergence stage and with a distribution rate of 3 + 1 L ha^{-1} of product. No pesticide treatment was performed.

2.1.4. Analysis Carried Out on Sunflower Plants and Seeds

The main morpho-phenological parameters were recorded (plant height, capitulum diameter determined on 10 plants plot^{-1} and then averaged, 1000 achene weight, emergence, flowering and harvesting maturity dates) as well as the production parameters of the parcel sample with the calculation of achene and oil yields per hectare. In particular, oil content was determined using the nuclear magnetic resonance (NMR) method and fatty acid composition with gas-chromatography of methyl-esterified compounds. Fatty acids composition was assessed to check if varieties were complying with the declared typology (HO or HL). For this reason, analyses were performed each year in all locations, but in an average sample for each hybrid.

In more detail, for NMR analysis all samples were dried in stove at 105 °C for 24 h, then 3–5 g of each sample was analyzed using a Minispec Mq 20. All setting parameters followed the ISO standards (ISO 8292-1, 2008).

Fatty acid contents (oleic and linoleic acids only) was determined by gas-chromatography technique, following the UNI EN ISO 5509:1998 and 5508:1998 standards to check the respondence with the declaration of hybrid producers. A FOCUS GC Thermo Scientific 2011 Gas Chromatograph was used, with a Rtx-2330 Cap. Column 30 m, 0.32 mm ID, 0.20 um type column (Restek, Milano, Italy).

Statistical data analysis, and in particular analysis of variance, was performed using DSAASTAT 1.019 software (excel extension by Onofri, 2017; University of Perugia; Italy). In this paper, the main statistically different results have been reported.

2.2. Cold Pressing of Sunflower Seed

The mechanical extraction was tested in the Biomasslab of D3A using a continuous screw press (Bracco company Ltd., Mod. Coter 205, Bergamo, Italy) with a power of 2.27 kW and a capacity of 15 kg h^{-1} (scheme in Figure 1). This press is representative of the systems with higher capacity employed in real application for the mechanical extraction of vegetable oil. The sunflower seed samples (5 kg each) were derived from the cultivation tests previously described. For each hybrid and each year, 5 kg were collected from each location. The samples were mixed, obtaining 20 kg representing the average seed for each year and hybrid. The extraction tests were carried out using 5 kg each test. The crude vegetable oil is released from the drainage holes while the extruder exits from the final hole in pellet form. The temperature was only monitored but not regulated during the extraction to simulate a real cold extraction process. The crude sunflower oil was then decanted in a storage tank for one day, and the sediment was removed. Mass balances were analyzed to measure the production of decanted crude sunflower oil and sunflower cake. Tests were run in triplicate.

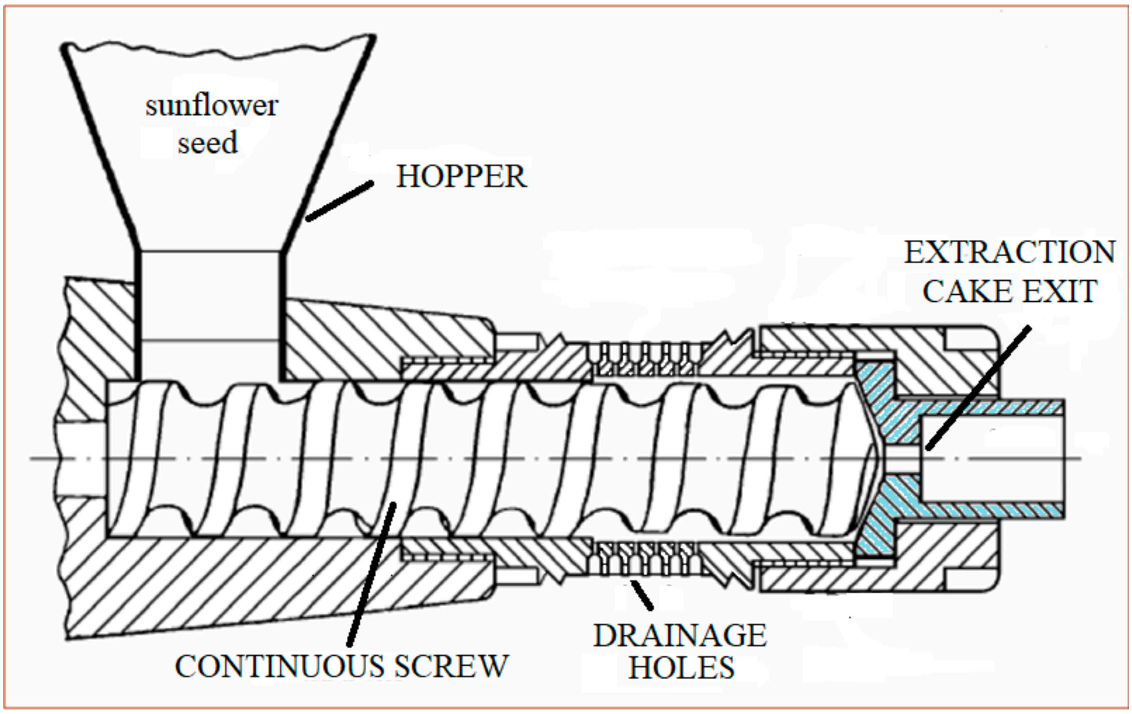

Figure 1. Scheme of the continuous screw press employed.

2.3. By-Products and Residues

The knowledge of the quality of by-products and residues is important for choosing the correct valorization with the aim to maximize the revenue and the sustainability. To this aim, a characterization has been carried out, but only on a limited number of samples taken in the bulk materials produced from the cultivation and extraction tests as reported below:

- 10 Sunflower extraction cakes
- 12 Sunflower stalks
- 12 Sunflower heads
- 4 Sunflower hulls

The hulls have been added because in some cases sunflower oil is produced from dehulled sunflower seeds. To this aim four sunflower seed samples have been dehulled.

The standard analytical methods for determining higher heating value (HHV), lower heating value (LHV), net heating value (NHV), moisture, ash, chlorine, sulfur, carbon, nitrogen, hydrogen contents, are the same employed by the authors in a previous study [8].

These results cannot be used for evaluating the different hybrids, but can be compared with a specific study carried out by the authors on a higher number of samples and hybrids to get useful indications about the possible valorization [8].

2.4. Scenario Definition

Taking into account all the results of this study and other researches carried out by other authors, it was possible to define a production scenario considering the dimension of specific case studies ("La Fonte" agricultural farm, "Vaccarini" agricultural farm, and Extension and Research Center in Agriculture "P. Rosati" of Università Politecnica delle Marche), representative of the small-medium farms typical of central Italy. The production scenario covers all the steps required for producing cold pressed sunflower oil (i.e., cultivation, cold pressing) in these small-medium farms, together with the mass balance of products and residues (cultivation residues, hulls, extraction cake), including the possible valorization of by-products and residues. The specific extraction systems employed by the farms and the hectares needed to efficiently use these systems were considered.

3. Results

Results of the tests carried out on sunflower cultivation and sunflower oil extraction are reported separately as follows.

3.1. Sunflower Seed Production

The multiannual thermo-pluviometric trends and differences of the yearly trends for each year and location are reported in Figure 2.

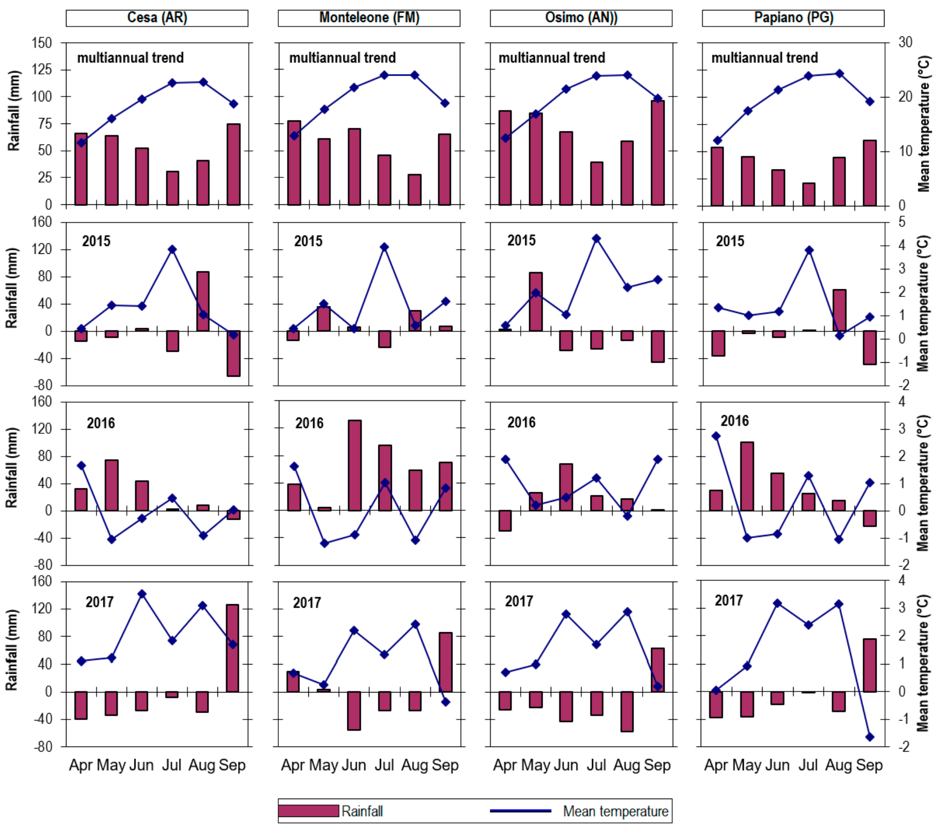

Figure 2. Multiannual thermo-pluviometric trends and yearly differences for the four locations.

The selected locations showed similar thermo-pluviometric trends. Cesa is characterized by lower temperatures (1 °C in average), while Papiano by lower rainfall (100 mm in average), especially in June and July. With respect to the multiannual trend, in 2015 there is an increase of 1 °C with a peak of +4 °C in July. Rainfall in 2015 showed a decrease, especially in the period related to flowering.

In 2016, there was a general increase in rainfall (from +104 mm in Papiano to +395 mm in Monteleone), with a significant amount in Spring with the only exception of Monteleone.

In 2017, rainfall was limited in all the locations, mainly in the Marche region and in June and July, with a temperature increase of more than 3 °C in Summer.

The results are reported not only as hybrid yield per year, but also as location per year and hybrid per location to highlight the significant effect of these interactions.

According to results (Table 1), 2016 is characterized by the highest crop yield because temperature and rainfall were more favorable to the sunflower crop along the entire cultivation cycle. In all the locations, crop yield was near or over 4 t ha^{-1} in 2016, with average differences of 15% and 21% from 2015 and 2017, respectively. Cesa in general showed the best production results in 2016 and 2017, while in 2015 it was the worst one among all the locations.

Table 1. Yield and plant height in different years and locations.

Location	Height (cm)						Crop yield (t ha^{-1}) [1]					
	2015		2016		2017		2015		2016		2017	
Cesa (AR)	173	bc	166	c	147	e	3.09	e	4.10	a	4.02	a
Monteleone (FM)	188	a	178	b	144	e	3.74	bc	3.96	ab	2.31	f
Osimo (AN)	171	bc	190	a	155	d	3.53	cd	4.14	a	3.16	e
Papiano (PG)	150	de	191	a	152	de	3.60	cd	4.14	a	3.42	d
Mean			167						3.60			
C.V. %			4.87						8.37			
LSD ($p \leq 0.05$)			6.60						0.28			

[1] Yield normalized at 9% moisture content.

Similarly, plant height results were also dependent by year and location. 2016 was the best year, showing, on average, 11 and 31 cm more with respect to 2015 and 2017. Monteleone and Osimo presented the highest values in 2015 and 2016, because of the abundant rainfall promoting an important vegetative growth. This growth, if not adequately supported, is not translated into good yield [11].

It is also interesting to analyze the interaction between years and hybrids (Table 2).

Table 2. Yield of hybrids in different years.

Hybrid	Crop Yield (t ha^{-1}) [1]					
	2015		2016		2017	
Mas 85.SU	3.28	cd	4.08	a	3.22	d
Mas 86.OL	3.61	b	4.18	a	2.88	e
NK Stradi	3.63	b	3.96	a	3.51	bc
SY Excellio	3.44	bcd	4.12	a	3.30	cd
Mean			3.60			
C.V. %			8.37			
LSD ($p \leq 0.05$)			0.24			

[1] Yield normalized at 9% moisture content.

As mentioned before, the 2016 showed the best crop yield for all the hybrids. In absolute terms NK Stradi resulted the best (3.70 t ha^{-1} in average), with +0.12 t ha^{-1} with respect to SY Excellio, +0,24 to MAS 86.OL, and +0.27 to MAS 85.SU.

Crop yield of different hybrids was affected also by location (Table 3), but with limited differences.

Table 3. Yield of hybrids in different locations.

Hybrid	Crop Yield (t ha^{-1}) [1]							
	Cesa		Mleone		Osimo		Papiano	
Mas 85.SU	3.99	a	3.20	c	3.50	ac	3.42	ac
Mas 86.OL	3.81	ac	3.24	bc	3.54	ac	3.64	ac
NK Stradi	3.62	ac	3.57	ac	3.72	ac	3.90	ab
SY Excellio	3.53	ac	3.35	ac	3.69	ac	3.92	ab
Mean	3.60							
C.V. %	8.37							
DMS $p \leq 0.05$	0.28							

[1] Yield normalized at 9% moisture content.

Mas 85.SU showed the highest yield at Cesa, but the result is not significantly different from the other hybrids. Similar results have been obtained in the other locations, while a statistically different result has been reported in Monteleone for MAS 85.OL.

The oil content of sunflower seed is generally more linked to genotype than location [12], but resulted, in this case, being dependent on both location and year (Table 4). Consequently, the same resulted for the potential oil yield, where the oil content is a component together with crop yield. The best year in terms of potential oil content (48.3%) resulted the 2016, in line with the crop yield. The differences with the other two years are 3.2% and 2.1%, with 2015 and 2017, respectively. Monteleone is the location where the highest value of potential oil content was registered, with differences of 0.8% and 1.6% from Cesa and Osimo, respectively.

Table 4. Potential oil content and oil yield related to hybrids, locations, and years.

Hybrid	Location	Oil Content (%) [1]						Potential Oil Yield (t ha^{-1}) [1]					
		2015		2016		2017		2015		2016		2017	
Mas 85.SU	Cesa	47.0	dl	49.7	bc	48.1	bi	1.42	lr	2.15	a	1.89	be
	M.Leone	44.7	ms	47.5	dk	46.1	hp	1.39	mr	1.66	em	0.98	uv
	Osimo	45.2	ls	45.5	kr	45.0	ls	1.37	nr	1.73	ck	1.23	qu
	Papiano	44.4	os	49.1	be	44.6	ns	1.24	qu	1.78	cj	1.30	os
Mas 86.OL	Cesa	45.9	ip	48.5	bg	43.3	st	1.48	kq	2.12	ab	1.39	mr
	M.Leone	45.8	jp	47.6	ck	47.0	dl	1.51	jq	1.68	dl	0.94	v
	Osimo	44.1	ps	46.0	hp	43.6	qt	1.45	kq	1.82	ch	1.05	sv
	Papiano	41.7	t	47.1	dl	44.1	ps	1.40	mr	1.76	cj	1.26	pt
NK Stradi	Cesa	41.8	t	48.3	bh	46.1	hp	1.03	tv	1.81	ch	1.85	cg
	M.Leone	47.0	el	49.9	b	48.8	bf	1.80	ci	1.83	ch	1.09	sv
	Osimo	48.6	bg	48.0	bj	46.4	go	1.65	en	1.66	em	1.53	ip
	Papiano	45.5	kr	51.9	a	47.9	bj	1.61	fn	2.00	ac	1.55	ho
SY Excellio	Cesa	45.1	ls	49.8	b	46.8	fm	1.16	rv	1.95	ad	1.63	en
	M.Leone	46.8	fn	49.2	bd	49.7	bc	1.59	gn	1.83	ch	1.01	tv
	Osimo	44.6	ms	47.1	dl	46.6	fn	1.40	mr	1.82	ch	1.43	lr
	Papiano	43.4	rt	48.7	bf	46.7	fn	1.47	kq	1.88	bf	1.60	fn
Mean		46.6						1.55					
C.V. %		2.41						9.12					
LSD ($p \leq 0.05$)		1.82						0.23					

[1] Values expressed on a dry matter content basis.

NK Stradi and SY Excellio showed the highest oil content, more than 47%. The lowest oil content was recorded in Papiano in 2015 for MAS 86.OL; the highest for NK Stradi in 2016 in the same location.

The highest potential oil yield was obviously recorded in 2016, by far the best year of the study. In line with the crop yield, Cesa is the best location also for potential oil yield (1.66 t ha^{-1} on average), with mean differences of 13%, 9%, and 5% with Monteleone, Osimo, and Papiano, respectively. NK Stradi was the most productive (1.62 t ha^{-1} on average), followed by SY Excellio (1.56 t ha^{-1}), MAS 85.SU (1.51), and MAS 86.OL (1.49). The best production performances were achieved in Cesa by MAS

85.SU, MAS 86.OL, and SY Excellio, while in Papiano by NK Stradi, (more than 2 t ha^{-1} of potential oil yield); the worst performances were achieved in Monteleone in 2017.

In Table 5 the analytical results of oleic and linoleic acid contents are reported. The contents of the different hybrids are perfectly in line with the values declared by the producers.

Table 5. Fatty acid content (only oleic and linoleic acid) in hybrids cultivated in different years.

Hybrid	2015		2016		2017	
	Oleic	**Linoleic**	**Oleic**	**Linoleic**	**Oleic**	**Linoleic**
Mas 86.OL	88.36	2.78	88.7	3.2	87.97	4.71
SY Excellio	85.08	4.91	85.9	4.6	85.50	6.09
MAS 85SU	33.24	55.68	38.37	49.60	37.60	49.90
NK Stradi	38.69	47.25	46.04	42.23	35.82	50.95

3.2. Cold Pressing of Sunflower Seed

The results of extraction tests are reported in Table 6.

Table 6. Results of the mechanical extraction tests.

Hybrid	Cold Pressed Oil (%)			
	2015	**2016**	**2017**	**Mean Value**
NK Stradi	35.7	38.7	36.9	37.1
SY Excellio	33.2	35.1	34.1	34.1
Mas 85.SU	35.0	37.1	35.5	35.9
Mas 86.OL	33.1	35.8	34.0	34.3

The values of sunflower oil extraction are in the range 33–39% of seed weight (9% standard moisture content), in line with scientific literature [8]. Considering the average yield calculated with the cultivation tests for each hybrid, it translates into a range of about 1.0–1.5 t ha^{-1} of cold pressed oil. This information represents a good estimation of the cold pressed sunflower oil obtainable in central Italy from 1 ha cultivation using suitable hybrids and a good estimation of the expected variability in different years. This variability can be reduced and better average results can be achieved by choosing the best hybrid for the specific location. Taking into account only the high oleic hybrids, the range of cold pressed oil is slightly lower (1.0–1.4 t ha^{-1}). The amount of sunflower extraction cake resulted about the complement to 100% (including 1% of sediment after decantation).

3.3. By-Products and Residues Characterization

The results of the energy characterization of by-products and residues are reported in Table 7, while the results of additional analysis carried out on extraction cake, and importantly also for animal feeding purposes, are reported in Table 8.

Table 7. Energy characterization of by-products and residues.

Material	NHV	HHV	LHV	Moisture	Ash	Cl	S	C	H	N
	MJ kg^{-1} a.r.	**MJ kg^{-1} d.m.**	**MJ kg^{-1} d.m.**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**	**(%)**
Extraction cake	19.012	22.102	20.654	7.5	5.0	0.08	0.09	52.0	7.4	5.0
Stalks	14.010	17.543	15.982	10.2	8.5	0.11	0.06	44.4	7.3	0.9
Heads	13.912	17.621	16.012	11.5	12.7	0.18	0.15	44.5	7.4	1.5
Hulls	19.102	22.201	20.698	6.9	3.5	0.06	0.07	54.3	7.4	1.5

NHV: Net Heating Value; HHV: High Heating value; LHV: Lower Heating Value; Cl: Chlorine; S: Sulphur; C: Carbon; H: Hydrogen; N: Nitrogen.

Table 8. Additional analysis carried out on extraction cake.

Material	Moisture (%)	Dry Matter (%)	Crude Protein (%)	Ether Extract (%)	Ash (%)	Crude Fiber (%)	NDF (%)	ADF (%)	ADL (%)
Extraction cake	7.0	93.0	23.2	12.6	4.9	22.2	45.8	32.2	11.5

The results are in line with a previous study carried out by the authors [8] in previous years. The sunflower cake could be used as feedstock for anaerobic digestion, showing a C/N ratio over 10, in line with the results of a study carried out by other authors [13]. The performance of this residue for biogas production can also be enhanced by pre-treatments [14,15]. The sunflower cake could also be employed for biofuel production in co-pyrolysis, as suggested by Shie [16], or for producing biomaterials by extrusion [17].

According to results and previous studies, the stalks can be used as feedstock for bioethanol production [18], for biogas production [19], and for biomaterials production [20]. Sunflower seed hulls can be employed by cofiring for energy production [21] or for obtaining bio-oil [22].

The results highlight how the extraction cake can be used for energy and other applications, but should be better valorized for feeding purposes as reported by different authors [23–25].

4. Discussion

Taking into account all the results of this study and other researches carried out by other authors, a previously mentioned production scenario has been defined, considering the dimension of the specific case studies reported in the Materials and Methods section.

According to information collected from these local sunflower oil producers in Marche region, in Figure 3 is reported as a possible scenario for central Italy, using the high-oleic hybrids considered in this study and suited for this area. Mass balance is reported together with an indication of the main market output (0.75-L glass bottled oil for food and extraction cake for feed) together with the possible alternative valorization (dotted line) of by-products and residues in the field of bioenergy and biomaterials, depending on the presence of a suitable industry in the area. The number of bovine heads is calculated, taking into account the use of 2 kg of extraction cake in substitution of about 1 kg of soybean meal [26]. The biogas produced from sunflower cake is calculated considering a production of 200 L CH_4 kg^{-1} [27]. For bioenergy and biomaterials, only the raw material in input is reported because the production is strictly linked to the conversion technology.

According to the scenario, 30 ha cultivated with sunflower are needed to produce the amount of seed allowing a suitable yearly use of the oil extraction system (employed in the case studies) from a technical-economical point of view. This surface is perfectly in line with the situation of many areas in central Italy, where sunflower is commonly cultivated and it is very likely to satisfy this production within a short distance (few kilometers) from the oil extraction system. This makes it possible to improve sustainability by limiting the seed transportation distance and to implement traceability, aspects really appreciated by the customers, both for food and energy productions. The reported market output is interesting and far higher if compared to the simple sunflower seed production, but the success is partly linked to the capacity of finding a suitable market for both sunflower oil and extraction cake. In many cases, this latter should be possible due to the presence of many livestock farms in central Italy, allowing the allocation of a related small amount of extraction cake. When not possible, the biogas use of sunflower cake is a viable option due to the presence of many small biogas plants. Stalks, heads, and eventually hulls, are quantified in Figure 3 based on the work of Duca et al. in 2015 [8], and could represent an additional market output if employed for energy application or for biomaterials, but the presence of these industries in nearly locations is required to make these options profitable.

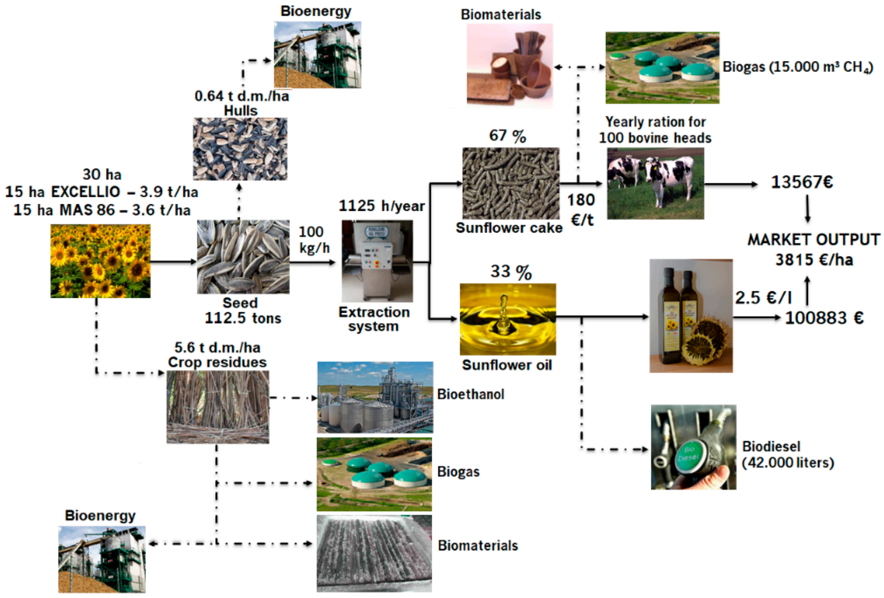

Figure 3. Mass balance and market output of a small local system of sunflower cold pressed oil production. Possible alternative valorization options of residues and byproducts are indicated with dotted line.

5. Conclusions

The results of the study highlight how the production of cold pressed sunflower oil is an interesting option in central Italy for the farmers. It is possible to create a complete food supply chain within the farm, avoiding many additional passages and maintaining all the value for the farmer. Interestingly, is also possible to valorize the productions in terms of bioenergy and biomaterials. It is important to use suitable hybrids for obtaining good yield, but also the cold extraction performances are important because it also affects the quality of by-products and residues. The possibility to employ extraction cake for feeding purposes or for biogas is also interesting in terms of sustainability and traceability.

The results can be a support for small-medium agricultural companies, typical of the studied area, producing sunflower oil or interested in this production. It can be also useful for policy makers interested in supporting local and high-quality food productions.

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