International Food Research Journal 23(2): 583-591 (2016)
Journal homepage: *http://www.ifrj.upm.edu.my*

Physicochemical composition of tomato seed oil for an edible use: the effect of cultivar

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Article history

Received: 16 December 2014
Received in revised form: 7 May 2015
Accepted: 1 August 2015

Keywords

Fatty acid methyl esters
Tomato cultivars
Tomato seed oil
Vegetable edible oil

Abstract

The effect of cultivar on tomato seed oil (TSO) composition of three industrial cultivars (Principe Borghese, Rebelion F1 and San Marzano) grown in Calabria Region (Southern Italy) was investigated. Nitrogen (N) and crude protein (CP) were determined on defatted dried seeds and the CP content was found to be useful for animal feed (35.02% - 40.94%). Other analyses were: oil content on dried seeds, refractive index (RI), free acidity (FA), spectrophotometric characteristics (i.e. K232nm, K266nm, K270nm, K274nm, ΔK), oil stability index (OSI), p-anisidine value (p-AV), color, relative density (RD), fatty acid methyl ester (FAME) composition. The findings strongly showed significant differences among cultivars and consequently a significant influence of the cultivar factor on the physicochemical properties of the tomato seed oil for an edible use. Rebelion F1 produced the worst seed oil in terms of oil content (19.84%), FA (7.77%), OSI (2.07 h), K232nm (0.0733), K270nm (1.2570), p-AV (3.93), cis-oleic acid (17.16%). Rebelion F1 also showed the highest essential fatty acid content (EFA) (62.67%) and the lowest mono-unsaturated fatty acid content (MUFA) (17.85%).

Introduction

The physicochemical properties of a vegetable oil are a criterion of its acceptability for an edible use. An edible vegetable oil is more attractive for consumers because, in the common way of thinking, it has lower health risks than animal fats. Free acidity, spectrophotometric indexes, OSI, color and FAMEs are among the main parameters that allows consumers to recognize the acceptability of a vegetable oil for an edible use.

The tomato is one of the most studied plants. Studies have been conducted on various aspects of the tomato fruit: aroma composition (Alonso *et al*., 2009a; Selli *et al*., 2014), volatile compounds of traditional and virus-resistant breeding lines of Muchamiel tomatoes (Alonso *et al*., 2009b); carotenoids accumulation during ripening (Riggi *et al*., 2008); carotenoids in dried tomato peel (Albanese *et al*., 2014); the effect of 1-methylcyclopropene on quality and storability of cherry tomato (Islam *et al*., 2012a). The effect of breathable film for packaging (Islam *et al*., 2011) and the effect of temperature on the quality and storability of tomatoes (Islam *et al*., 2012b) have also been studied. Cinquanta *et al.* (2014) proved that combined hot air–microwave heating significantly reduces the drying time (up to 50 %), if compared with the convective system alone.

The tomato industry produces tons of tomato seeds that constitute a problem for disposal. Instead of disposal, tomato seeds could be used as a source of vegetable oil for edible use. One of the advantages of the possible use of TSO is that it is not necessary to cultivate a specific area for its production but you can use seeds discarded after tomato sauce production. In addition, the price of a cheap edible vegetable oil increases if it can be used also for industrial purposes but TSO has not a widespread use at present.

The effect of cultivar has been shown on other vegetable oils and in particular on olive oil and its composition: fatty acids (Rondanini *et al*., 2011; Ceci and Carelli, 2007), tocopherols (Ceci and Carelli, 2010), sterols (Giuffrè *et al*., 2012; Giuffrè and Louadj, 2013), fatty alcohols (Giuffrè, 2014a; Giuffrè, 2014b), wax esters (Giuffrè, 2013a; Giuffrè, 2014c), triglycerides (Giuffrè, 2013b; Giuffrè, 2014d). The effect of cultivar has also been shown on policosanol content (Giuffrè and Capocasale, 2014) and on sterol content (Giuffrè and Capocasale, 2016) of the TSO. In this paper the effect of cultivar on physicochemical properties of TSO for an edible use is discussed to consider the tomato seeds as a by-product and not as a waste. In the existing literature about TSO there is a scarce differentiation between

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cultivars.

Materials and Methods

Vegetable material

Fruits of three tomato cultivars (Principe Borghese, Rebelion F1 and San Marzano) were manually and randomly collected in the harvest years 2012-2013-2014 (middle July). Plants were grown as field crops in three neighbouring fields (to exclude the environmental influence) at Roccella Ionica on the east coast of the Reggio Calabria Province, (Southern Italy).

The soil was plowed to a depth of 40 cm and was fertilized in pre-transplant (March) with organic fertilizers (12 q/ha) and chemical fertilizers NPK 20:20:20 (400 kg/ha). Seedlings were transplanted in April and spaced 70 cm within the row and 80 cm between the rows. Irrigation was conducted at intervals of 10 days (April-May) and of 7 days (June), using 1.5 L/plant. An automatic system irrigated plants considering both evaporation and transpiration. After fruit pressing, seeds were separated from tomato juice.

Chemicals

Authentic standard samples of FAMEs, were from Sigma-Aldrich, Steinheim-Germany. All other reagents of spectrophotometric and analytical grade were from Panreac (Barcelona, Spain).

Tomato seed oil extraction

Tomato seed oil extraction was conducted as described in a previous paper (Giuffrè and Capocasale, in press).

Determination of nitrogen and crude proteins

The protein N were converted to $(NH_4)_2SO_4$ after digestion in H_2SO_4 at 370 °C with the addition of K_2SO_4 and a Cu catalyst to enhance the reaction rate. Ammonia is liberated by alkaline steam distillation and quantified titrimetrically with standardized acid (HCl 0.1N). The efficiency of the digestion is increased by the aluminium block heaters. Crude proteins = Nitrogen x 6.25 (AOAC, No 988.05).

Determination of refractive index

The RI is defined as light passes from one transparent medium to another, in our case from oil to air. Generally the RI is related to the density of the oil. The RI was determined by an Abbe refractometer at 20 °C according to AOAC No 921.08 method (AOAC No 921.08).

Determination of free acidity

FA is the quantification of the free fatty acids. It was determined as described in the Annex II of the CONSLEG 2003 for olive oil analyses (Consleg, 2003). An aliquot of TSO was dissolved in diethyl ether/ethylic alcohol (1:1, v/v) and titrated with a 0.1 N aqueous NaOH solution. Results were expressed as g of oleic acid / 100 of TSO.

Spectrophotometric investigation in the ultraviolet

The measure of the absorption bands in the range of 200-300 nm gives qualitative information about the vegetable oil. The lower the absorption the better the oil's chemical quality. High values are a consequence of a refining or adulteration process and conjugated dienes and trienes are also formed. Hydroperoxides are also formed because of the oxygen fixation in the FAME double bond position. Spectrophotometric indexes in the ultraviolet were determined as suggested by the Annex IX of the CONSLEG 2003 for olive oil analysis (Consleg, 2003). A 1% oil in isooctane solution (p/v) was prepared and extinctions were measured at 232, 266, 270 and 274 nm. A UV/Vis Spectrometer model Lambda 2, Perkin Elmer, Waltham, Massachusetts U.S.A., was used.

Determination of oil stability index

In brief, the OSI is the induction time to oil oxidation. It is the determination of the resistance of the oil to oxidative phenomena. In more detail, vegetable oils or fats are submitted to a stress by combined high temperature and oxygen; after the destruction of fatty acids, the secondary oxidation products are carried by a stream of air to the measuring vessel where the time for their production (induction time) is measured. OSI analysis was conducted in a Rancimat apparatus model 679 (Metrohm, Herisau - Switzerland). A 3.0 g aliquot of oil was weighed in the glass reaction vessel. The measuring vessel was filled with a 60 mL volume of bi-deionized water. The temperature was set at 120 °C. Filtered air was bubbled through the oil at a rate of 10 L/h. The speed chart was set at 1 cm/min.

Determination of p-anisidine value

The p-AV indicates the unvolatile aldehyde content, mainly 2-alchenals present in the oil, i.e. the products of secondary oxidation. The p-AV analysis was conducted as described by the Norme Grassi e Derivati method NGD C 36-79 (NGD, 1976), by reading the optical density of the oil at 350 nm in a UV/Vis Spectrometer model Lambda 2, Perkin Elmer, Waltham, Massachusetts U.S.A.

Determination of color

Determination of color was conducted by a Minolta Chroma Meter CR-400 instrument. A Minolta transparent (base and side) special glass container (5.0 cm Ø , 6.0 cm high) with a cylindrical shape was used. One centimeter of TSO was added to this glass container and the color was determined. A further 1 cm was added and color was determined again. These two measurements were conducted in triplicate. The CIELab scale was used. L^* (brigthness) ranges between 0 (black) to 100 (white); a^* ranges between -90 (green) to +90 (red) and b^* ranges between -90 (blue) to +90 (yellow).

Determination of fatty acid methyl esters by GC

FAME were prepared to determine the fatty acid composition by GC as described in Annex X, method A, of the CONSLEG 2003 for olive oil analysis. FAME are formed by transesterification with methanolic potassium hydroxide as an intermediate stage before saponification takes place (Consleg, 2003). A Fisons Instruments GC 8000 gas chromatograph equipped with a split-splitless injector and a F.I.D. (Flame Ionization Detector) was used. Both injector and detector temperatures were set at 250 °C. The analytical column was a 30 m x 0.53 mm i.d. x 0.20 μm film thickness, Supelcowax TM-10. The carrier gas used was helium with a flow rate of 75 Kpa. Auxiliary gases: air (150 Kpa) and hydrogen (100 Kpa). The oven temperature program was: 120 °C (1 min), ramp 2 °C/min up to 160 °C, (2 min), 5 °C/min up to 230 °C (10 min). The identification of the compounds was based on a comparison of retention indices with those of authentic samples and with literature data.

Statistical analysis

Analysis were conducted in triplicate for each year and for the 2012-2013-2014 harvest years, data are presented as the means of three years. Statistical significance was assayed using an one-way analysis of variance (ANOVA); the Tukey test was used to determine the differences between cultivars at $P < 0.05$. The cultivar effect was taken into consideration. SPSS version 15.0 (SPSS Inc., Chicago, IL, U.S.A.) was used to determine the significant differences and for cluster analysis. All other statistical analyses were conducted by Excel for Windows software (2007 version).

Results and Discussion

Oil content

The physical and chemical properties of the studied TSO are reported in Table 1. The oil quantity, calculated on dry seed weight, ranged from 19.84% found in Rebelion F1 to 23.44% found in Principe Borghese. Other Authors carried out the TSO extraction with different systems and found: 35.3%, 36.4%, 36.9% after supercritical acetone extraction at 513, 515 and 518°K respectively (Demirbas, 2010); 30.3% after Soxhlet extraction with chloroform/ methanol 2:1 (Kulkarni *et al.*, 2012); 23.1% after accelerated solvent extraction with ethanol, 20.0% after accelerated solvent extraction with ethanol and 17.3% after supercritical carbon dioxide extraction (Eller *et al*., 2010). A lower oil quantity (17-18%) was extracted by pressing the dried tomato seeds (Giuffrè *et al*., 2015).

Nitrogen and crude protein

In the present work, the nitrogen content was determined on the defatted tomato seed powder of the three cultivars. The highest N quantity was found in San Marzano (6.55%) i.e. 16.96% more than in Principe Borghese the cultivar with the lowest amount (5.60%), (Table 1). The CP content was calculated on the basis of the N content and consequently the ratios among the cultivars are the same. In the defatted tomato seeds the CP content was 35.02% in Principe Borghese, 38.20% in Rebelion F1 and 40.94% in San Marzano. After oil extraction from tomato seeds the remaining dry matter can also be used. The defatted tomato seed cake being rich in protein, minerals and lysine contents may be helpful as a supplement in improving the quality of the farm animal feed (Rao, 1991). Scerra *et al.* (2010) studied the diet of lamb by preparing a meal mainly containing alternatively soybean (CP 19.50%), broad bean (CP 19.92%) and pea (CP 19.56%). Musalia *et al.* (2000) studied seed cake for lamb feed and found 33.68% CP in neem seed kernel cake and 43.48% in groundnut cake. CP results obtained from the seeds of the three tomato cultivars studied in this paper showed values higher than those found in seeds commonly used for animal feed therefore, the defatted tomato seed cake could be used for animal feed.

Refractive index

The RI was: 1.4662 in Rebelion F1, 1.4632 in Principe Borghese and 1.4581 in San Marzano. Lazos *et al.* (1998) found a RI value of 1.4603 in the crude oil and 1.4610 in the purified oil from tomato seeds produced in Greece; a similar value (1.4623) was found in Egyptian TSO (Gad *et al.*, 1968). Kulkarni *et al.* (2012) found 1.4700 as RI in TSO from plants cultivated in India in oil extracted by Soxhlet and analyzed at 25 °C; a very similar value (1.4708

Table 1. Physicochemical composition of tomato seed oil (mean values ± Standard Deviation). Means in the same line with different letters differ significantly. Significance level: * P < 0.05; *** P < 0.001

	Principe Borghese	Rebelion F1	San Marzano	Sign.
Nitrogen (%)	5.60±0.11c	6.11±0.06b	6.55±0.09a	* * *
Crude Protein (%)	35.02±0.67c	38.20±0.34b	40.94±0.56a	* * *
Oil content (DW%)	23.44 ± 0.19a	19.84 ± 0.14c	22.71 ± 0.16b	* * *
Refractive Index (n^{20})	1.4632 ± 0.0003b	1.4662 ± 0.0041a	1.4581 ± 0.0001c	* * *
Free Acidity (g %)	3.15± 0.01b	7.77 ± 0.01a	1.71 ± 0.01c	* * *
$K_{232\ nm}$	1.615± 0.06ab	1.731 ± 0.08a	1.470 ± 0.09c	*
$K_{266\ nm}$	0.5680± 0.00a	0.5790 ± 0.01a	0.4803 ± 0.00b	* * *
$K_{270\ nm}$	1.2500± 0.01a	1.2570 ± 0.00a	0.8823 ± 0.00b	* * *
$K_{274\ nm}$	1.2500± 0.01a	1.2307 ± 0.00b	0.8133 ± 0.00c	* * *
ΔK	0.34 ± 0.00b	0.35 ± 0.00a	0.24 ± 0.00c	* * *
OSI - 120 °C (h)	3.90 ± 0.06b	2.07 ± 0.04c	4.72 ± 0.06a	* * *
p – Anisidine Value	1.21 ± 0.03c	3.93 ± 0.03a	2.01 ± 0.02b	* * *
*L** (1 cm)	28.50 ± 0.00a	26.95 ± 0.00c	28.37 ± 0.00b	* * *
*a** (1 cm)	1.98 ± 0.00c	3.55 ± 0.00a	2.21 ± 0.00b	* * *
*b** (1 cm)	7.55 ± 0.00b	5.04 ± 0.00c	7.62 ± 0.00a	* * *
*L** (2 cm)	24.87 ± 0.00a	24.32 ± 0.00c	24.55 ± 0.00b	* * *
*a** (2 cm)	1.34 ± 0.00c	1.59 ± 0.00b	1.63 ± 0.00a	* * *
*b** (2 cm)	1.55 ± 0.00b	0.58 ± 0.00c	1.65 ± 0.00a	* * *

n20) was found in Romania in TSO obtained by a cold pressed extraction system (Botineştean *et al*., 2012). RI values above 1.47 were found in Petomech cultivar from Brazilian TSOs extracted by hot break system (1.4733) and by cold break system (1.4720) (Cantarelli *et al*., 1993). A RI of 1.4733 was found in Turkish TSOs after Soxhlet acetone extraction and 1.4714 after Supercritical acetone extraction (Demirbas, 2010).

Free acidity

FA is an important parameter for vegetable oil evaluation. High acidity is a negative condition for the edible use of the vegetable oil. FA is a symptom of the lipase activity on triglycerides. The oil deterioration causes a scarce digestibility of the edible oil. Rebelion F1 showed the worst value (7.77%), i.e. 2.46 times more than Principe Borghese (3.15%) and 4.54 times more than San Marzano (1.71%). As a consequence, before being used for an edible purpose all the studied TSOs have to be deacidified but with different priorities and costs. For edible olive oil a maximum of 0.8% is required for the extra virgin type and a maximum of 2.0 for the virgin type (EU, 2013; COI, 2013).

Spectrophotometric determination in the ultraviolet

No data from other Authors was found on the spectrophotometric investigation in the ultraviolet regarding to the TSO. At K232nm, all samples showed values well within the maximum stated by the Official Journal of the European Union (≤ 2.5 for an extra virgin olive oil) (EU, 2013). Rebelion F1 had the highest value (1.731) and the lowest was in San Marzano (1.470). Rebelion F1 presented the highest value (1.2570) also at K270nm. All samples exceeded the maximum at K270nm for a virgin olive oil (≤ 0.25) and the maximum for an olive pomace oil (≤ 1.70). The ΔK was: 0.34 for Principe Borghese, 0.35 for Rebelion F1 and 0.24 for San Marzano, always exceeding the 0.01 for an extra virgin olive oil and the 0.18 for an olive pomace oil. These results describe an oxidized oil, probably this is a consequence of the extractive method and the prolonged contact with heating.

Oil stability index – OSI (h)

The highest OSI (4.72 h) was found in San Marzano, the cultivar with the lowest unsaturated fatty acid (UFA) content. Rebelion F1 produced the least resistant oil to oxidation (2.07 h) and with the highest UFA content. A high relationship was found between OSI and FA (R = 0.994). Lazos *et al*. (1998) at the same temperature but with a 20 L/h air flow found 5.15 h for a crude TSO and 4.9 for a purified TSO. However, Lazos *et al*. (1998) do not specify the amount of oil weighed in the glass reaction vessels.

p-anisidine value

A p-AV of 10 can be considered the maximum limit for a good raw edible vegetable oil. As for other physicochemical data, the highest p-AV was found in Rebelion F1 (3.93) indicating the worst oil also from this point of view. All samples showed a p-AV below 10, similar to the results of other Authors who found values below 10 in vegetable oil: 6 in extra virgin olive oil, 3 and 4 in virgin olive oils, 6 in refined olive oil, 10 in a refined vegetable oil blend with large commercial importance in Portugal, based mostly on sunflower oil (Casal *et al*., 2010). Lee *et al*. (2007) found 0.8 in a refined soybean oil, 6.9 in a refined

Table 2. Fatty acid composition of tomato seed oil (mean values± Standard Deviation). Means in the same line with different differ significantly. Significance level: n.s. = not significant; $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$

	Principe Borghese	Rebelion F1	San Marzano	Sign.
myristic	0.13 ± 0.01a	0.08 ± 0.01b	0.10 ± 0.01b	* * *
myristoleic	0.01 ± 0.01c	0.07 ± 0.01b	0.25 ± 0.02a	* * *
palmitic	12.97 ± 0.02c	13.92 ± 0.02a	13.12 ± 0.01b	* * *
palmitoleic	0.34 ± 0.01b	0.38 ± 0.02a	0.35 ± 0.02ab	*
heptadecanoic	0.40 ± 0.02a	0.40 ± 0.02a	0.34 ± 0.01b	* *
heptadecenoic	0.08 ± 0.02ab	0.07 ± 0.01a	0.11 ± 0.01b	*
stearic	5.74 ± 0.02b	4.61 ± 0.04c	8.17 ± 0.01a	* * *
trans-oleic	0.05 ± 0.01b	0.08 ± 0.01a	0.05 ± 0.01b	* *
cis-oleic	25.71 ± 0.02b	17.16 ± 0.04c	27.98 ± 0.02a	* * *
cis-linoleic	51.90 ± 0.04b	61.00 ± 0.02a	47.11 ± 0.04c	* * *
linolenic	1.99 ± 0.02a	1.67 ± 0.03b	1.64 ± 0.01b	* * *
arachidic	0.43 ± 0.02a	0.36 ± 0.01b	0.58 ± 0.02a	* * *
eicosenoic	0.10 ± 0.02a	0.08 ± 0.01a	0.09 ± 0.01a	n.s.
behenic	0.14 ± 0.03a	0.11 ± 0.02a	0.13 ± 0.01a	n.s.
SFA	19.82 ± 0.01b	19.48 ± 0.09c	22.43 ± 0.02a	* * *
UFA	80.18 ± 0.01b	80.52 ± 0.09a	77.57 ± 0.02c	* * *
UFA/SFA	4.05 ± 0.00b	4.13 ± 0.02a	3.46 ± 0.00c	* * *
MUFA	26.29 ± 0.05b	17.85 ± 0.06c	28.83 ± 0.03a	* * *
Di-UFA	51.90 ± 0.04b	61.00 ± 0.02a	47.11 ± 0.04c	* * *
PUFA (EFA)	53.89 ± 0.04b	62.67 ± 0.02a	48.75 ± 0.03c	* * *
18:2ω6/18:3ω3	26.13 ± 0.20c	36.53±0.66a	28.78±0.12b	* * *

sunflower oil and 5.8 in virgin olive oil.

Color

Color affects consumers' decision making. As most, if not all, refined oils are sold on the basis of their it is necessary to monitor each stage of the refining process to establish if the correct color has been reached (Belbin, 1993). In the edible vegetable oil used for frying, the oxidation proceeds vigorously and oxygen seems to attack unsaturated fatty acids in triacylglycerols, darkening the oil while amino acids react with already existing carbonyls (Totani *et al*., 2006).

The L^* value showed that Principe Borghese seed oil both in the 1 cm (28.50) or in the 2 cm volume (24.87), was lighter than San Marzano and than Rebelion F1. The a^* value indicated that the Rebelion F1 seed oil was redder than other when the glass container was filled up to 1 cm (3.55), whereas San Marzano seed oil was the reddest when the glass container was filled up to 2 cm (1.63). The b^* value was higher in San Marzano (7.62 / 1 cm and 1.65 / 2 cm) and lower in Principe Borghese (1.98 / 1 cm) and in Rebelion F1 (0.58 / 2 cm).

FAMEs

Fourteen fatty acids were detected, with a chain length ranging from 14 to 22 carbon atoms. Linoleic acid was found in the highest quantity: 51.90% in Principe Borghese, 61.00% in Rebelion F1 and 47.11% in San Marzano. The second most represented was cis oleic acid which was highest in San Marzano (27.98%) and lowest in Rebelion F1 (17.16%); similar to Greek TSO in which 22% oleic acid was found (Lazos *et al*. 1998; Giannelos *et al*., 2005). Palmitic acid was 13-14% of the total. The essential fatty acid (EFA) content was 53.89% in Principe Borghese, 62.67% in Rebelion F1 and 48.75% in San Marzano: quantities different to those of some common and uncommon vegetable oils: 2.5-3.0% in virgin olive oil (Giuffrè *et al*., 2010); 20-24% in almond seed oil (Piscopo *et al*., 2010), 72.60% in passiflora seed oil (Giuffrè, 2007). Saturated fatty acids (SFAs) were always lower than 22.50%, similar to a virgin olive oil (Giuffrè *et al.*, 2010; Louadj and Giuffrè, 2010).

ANOVA analysis

Differences were statistically considered for each cultivar ($P < 0.05$) and data are evaluated row by row. Principe Borghese showed the very highly significant highest: oil content, L^*, and linolenic acid. Rebelion F1 showed the very highly significant worst values for FA, K232, K266, K270, K274, ΔK, OSI, p-AV, cis-oleic acid. San Marzano showed the very highly significant best values for N, CP and cis-oleic acid. FA was significantly different in the three TSO and also in this case Rebelion F1 largely showed the worst value and San Marzano had the best value. The p-AV was significantly different in all TSO and again Rebelion F1 had the highest value. The induction time was very highly significantly different for the three studied cultivars. The L^* value (lightness) had a significant difference among the TSO cultivars both in the 1 cm or in the 2 cm volume. The a^* value (redness) was significantly different

Table 3. Correlation matrix of physicochemical parameters of the TSO from the three cultivars: Principe Borghese, Rebelion F1 and San Marzano

Variables	Nitrogen (%)	Crude Protein (%)	Oil content (DW%)	Refractive Index (n20)	Free Acidity (g %)	K232 (nm)	K266 (nm)	K270 (nm)	K274 (nm)	ΔK	OSI (h)	*p* – Anisidine Value	L* (1 cm)	a* (1 cm)	b* (1 cm)	L* (2 cm)	a* (2 cm)	b* (2 cm)
Nitrogen (%)	1																	
Crude Protein (%)	1.000	1																
Oil content (DW%)	-0.233	-0.234	1															
Refractive Index	-0.589	-0.589	-0.649	1														
Free Acidity (g %)	-0.186	-0.185	-0.912	0.904	1													
K232 nm	-0.443	-0.442	-0.769	0.985	0.963	1												
K266 nm	-0.785	-0.785	-0.419	0.963	0.754	0.903	1											
K270 nm	-0.835	-0.835	-0.340	0.936	0.696	0.863	0.996	1										
K274 nm	-0.864	-0.864	-0.287	0.915	0.655	0.834	0.990	0.998	1									
ΔK	-0.797	-0.797	-0.401	0.957	0.742	0.894	1.000	0.998	0.993	1								
OSI (h)	0.261	0.261	0.878	-0.934	-0.997	-0.981	-0.803	-0.749	-0.711	-0.791	1							
p – Anisidine Value	0.327	0.327	-0.995	0.572	0.868	0.703	0.329	0.247	0.193	0.310	-0.827	1						
L* (1 cm)	-0.118	-0.118	0.993	-0.733	-0.954	-0.838	-0.523	-0.448	-0.398	-0.506	0.928	-0.977	1					
a* (1 cm)	0.178	0.178	-0.998	0.691	0.934	0.804	0.470	0.393	0.341	0.453	-0.903	0.988	-0.998	1				
b* (1 cm)	-0.019	-0.019	0.977	-0.797	-0.979	-0.888	-0.605	-0.534	-0.487	-0.589	0.960	-0.951	0.995	-0.987	1			
L* (2 cm)	-0.613	-0.614	0.911	-0.277	-0.662	-0.437	-0.008	0.078	0.133	0.012	0.602	-0.947	0.857	-0.886	0.801	1		
a* (2 cm)	0.938	0.938	-0.556	-0.273	0.166	-0.105	-0.522	-0.593	-0.637	-0.539	-0.089	0.634	-0.454	0.507	-0.364	-0.849	1	
b* (2 cm)	0.042	0.042	0.962	-0.832	-0.990	-0.915	-0.652	-0.585	-0.539	-0.637	0.975	-0.931	0.987	-0.976	0.998	0.763	-0.306	1

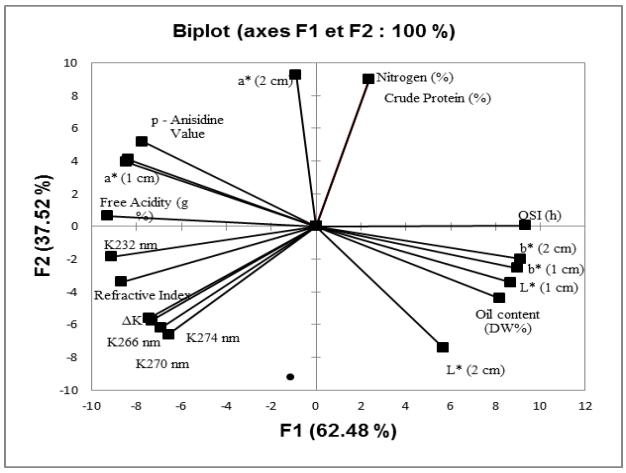
Table 4. Correlation matrix of fatty acids of the TSO from the three cultivars: Principe Borghese, Rebelion F1 and San Marzano.

Variables	myristic	myristoleic	palmitic	palmitoleic	heptadecanoic	heptadecenoic	stearic	trans oleic	cis oleic	cis linoleic	linolenic	arachidic	eicosenoic	behenic	SFA	UFA	UFA / SFA	MUFA	Di-unsaturated	PUFA (EFA)	18:2/18:3
myristic	1																				
myristoleic	-0.350	1																			
palmitic	-0.882	-0.133	1																		
palmitoleic	-0.923	-0.038	0.995	1																	
heptadecanoic	0.115	-0.971	0.367	0.277	1																
heptadecenoic	0.127	0.885	-0.580	-0.500	-0.971	1															
stearic	0.200	0.848	-0.638	-0.562	-0.951	0.997	1														
trans-oleic	-0.803	-0.277	0.989	0.971	0.500	-0.693	-0.744	1													
cis-oleic	0.668	0.463	-0.940	-0.904	-0.662	0.823	0.862	-0.980	1												
cis-linoleic	-0.553	-0.587	0.881	0.832	0.764	-0.897	-0.927	0.941	-0.989	1											
linolenic	0.884	-0.747	-0.559	-0.636	0.565	-0.351	-0.281	-0.432	0.243	-0.100	1										
arachidic	0.200	0.848	-0.639	-0.563	-0.950	0.997	1.000	-0.745	0.863	-0.927	-0.281	1									
eicosenoic	0.993	-0.240	-0.930	-0.961	0.000	0.240	0.311	-0.866	0.749	-0.645	0.825	0.311	1								
behenic	0.954	-0.052	-0.983	-0.996	-0.189	0.419	0.485	-0.945	0.861	-0.778	0.703	0.485	0.982	1							
SFA	-0.009	0.940	-0.463	-0.377	-0.994	0.991	0.978	-0.588	0.738	-0.828	-0.475	0.978	0.105	0.291	1						
UFA	0.009	-0.940	0.463	0.377	0.994	-0.991	-0.978	0.588	-0.738	0.828	0.475	-0.978	-0.105	-0.291	-1.000	1					
UFA/SFA	0.005	-0.939	0.467	0.381	0.994	-0.991	-0.979	0.592	-0.740	0.830	0.472	-0.979	-0.109	-0.295	-1.000	1.000	1				
MUFA	0.651	0.483	-0.932	-0.894	-0.679	0.835	0.873	-0.975	1.000	-0.992	0.222	0.874	0.734	0.849	0.753	-0.753	-0.755	1			
Di-UFA	-0.553	-0.587	0.881	0.832	0.764	-0.897	-0.927	0.941	-0.989	1.000	-0.100	-0.927	-0.645	-0.778	-0.828	0.828	0.830	-0.992	1		
PUFA (EFA)	-0.530	-0.609	0.867	0.816	0.782	-0.909	-0.937	0.931	-0.985	1.000	-0.072	-0.937	-0.624	-0.760	-0.843	0.843	0.845	-0.989	1.000	1	
18:2ω6/18:3ω3	-0.925	-0.033	0.995	1.000	0.272	-0.496	-0.558	0.969	-0.901	0.829	-0.640	-0.558	-0.962	-0.996	-0.372	0.372	0.376	-0.891	0.829	0.813	1

in the three cultivars ($P < 0.05$). The b^* value (yellow) was influenced by cultivar ($P < 0.05$) and San Marzano was the yellowest TSO, followed by Principe Borghese and Rebelion F1. Cis-linoleic, cis-oleic, palmitic and stearic, the four most represented FAMEs showed significant differences in all cultivars. All FAMEs with a percentage content lower than 2% (except myristoleic acid) showed partial significant differences or no differences in the three tomato cultivars. Saturated, unsaturated, monounsaturated, di-unsaturated and poly-unsaturated fatty acids were significantly different in all cultivars. As the three cultivars were grown in the same agronomical and microclimatic conditions, the cultivar effect explains the differences among the three studied TSO.

Correlation matrix

The correlation matrix among the first set of data is



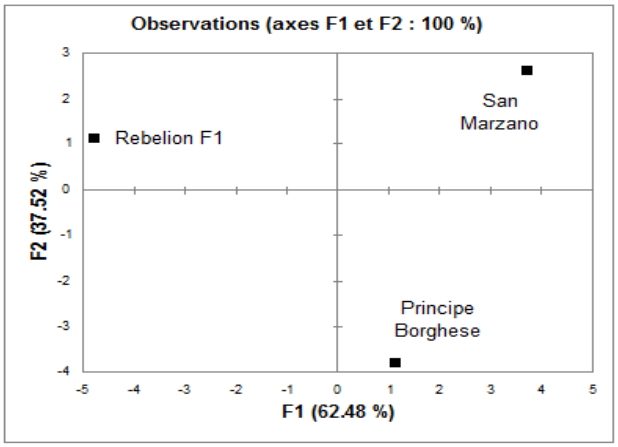
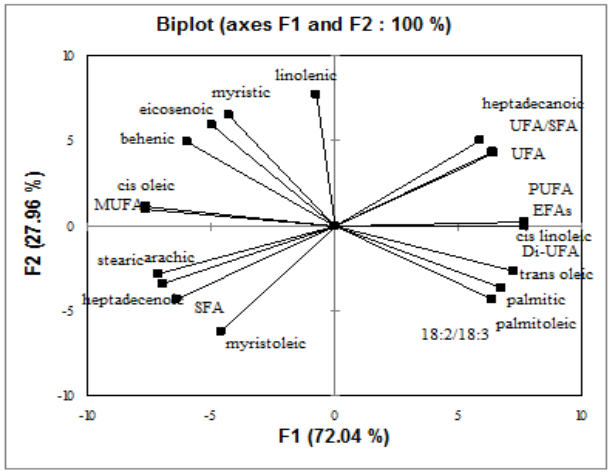


Figure 1. a - shows PCA of the TSO studied physicochemical properties and b - is the score plot of the PCA performed on the TSO studied physicochemical properties.



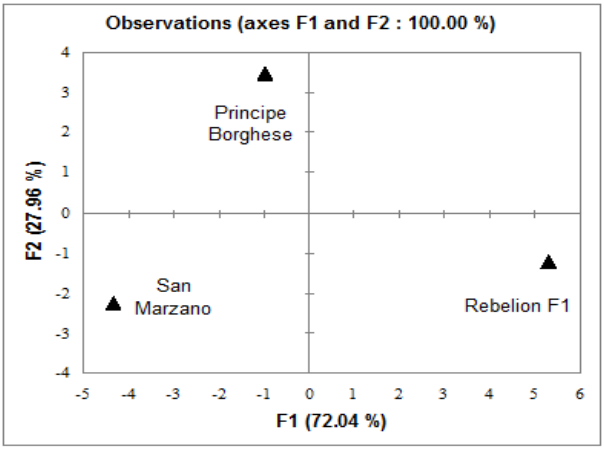


Figure 2. a - shows PCA of the TSO FAME composition and b – is the score plot of the PCA performed on the TSO FAME composition.

described in Table 3. The spectrophotometric indices were highly correlated and showed a R ranging from 0.834 to 1.000. OSI was negatively correlated with FA (R = - 0.997) and with p-AV (R = - 0.827). The correlation matrix of FAME (Tab. 4) showed that stearic acid is strongly correlated with arachidic acid (R = 1.000) and with PUFA (R = - 0.937). Palmitic acid was negatively correlated with cis-oleic acid (R = - 0.904) and MUFA (R = - 0.932).

PCA

All forty parameters studied in this paper were subjected to the PCA analysis. Only two Eigen values were obtained for each parameter which were higher than 1.00. All the values of all the parameters accounted 100% of the cumulative variance. In Figure 1 the first set of data is described (no-chromatographic data): their values (and the percentage of total variance) were 12.5 (62.48%) and 7.50 (37.52%). Visualization of the discrimination among cultivars on the plane of the first two functions led to a fairly good separation among the different groups. The three cultivars are represented on three different sides of the plane: Rebelion F1 was in the left top corner of the diagram, San Marzano was in the right top corner of the diagram and Principe Borghese was in the right bottom corner. The vector direction suggests that OSI was present at the expense of FA and of K232nm. In Figure.2 the FAME composition is described. The values accounted for 100% of the cumulative variance. Cis oleic acid was present at the expense of PUFA and EFA. Cis-oleic and MUFA were highly correlated.

Conclusions

The TSO studied in this paper were obtained by solvent extraction. The forty parameters proved that cultivar highly significantly influenced the physicochemical properties of the tomato seed oil for an edible use. TSO (San Marzano cv) showed the significantly best FA, spectrophotometric characteristics, OSI and cis-oleic acid content. Linoleic and linolenic acid were the lowest in San Marzano, this is positive because they are the most subject to oxidation. On the other hand the linoleic

and linolenic fatty acids are recognized to be two EFA, for this reason, TSO can be used as a dietary supplement in EFA deficient diets. The defatted seeds can be used for animal feed for their high CP content and San Marzano, again, showed the highest CP content.

Acknowledgements

This research was supported by PON01 01397 fund: "Agronomical, qualitative, technological and marketing evaluation of traditional tomato product transfer (peeled, cherry, sun dried, "piennolo") in innovative packaging for a market upgrading. Possibility of using industrial tomato waste (seeds and skins) for seed oil production as fuel and/or cosmetic applications and functional substances extraction".

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