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Short title: *Productive ability and seed quality of sesame*

AGRONOMIC PERFORMANCE AND GRAIN QUALITY OF SESAME (*SESAMUM INDICUM* L.) LANDRACES AND IMPROVED VARIETIES GROWN IN A MEDITERRANEAN ENVIRONMENT

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SUMMARY

Sesame seeds are an excellent raw material for a number of sectors (food and non-food) of industry, for which there is a consolidated deficit in Italy and in other European Union (E.U.) countries. For this reason, a 2-years field experiment was conducted in Italy (Mediterranean to sub-tropical climate) to compare the agronomic performance (phenology, morphological and productive traits) and grain quality (oil and its main constituents, protein of defatted flour, fibre) of two commercial varieties (Pachequino and Yori 77) and three landraces, one of Turkish origin and two Sicilian (Ispica and Modica). The landraces evidenced earliness and the greater height of insertion of first capsule, whereas the variety 'Pachequino' was the most productive. Turkish and 'Ispica' landraces and 'Yori 77' variety provided seeds with greater lipid content and protein content of defatted flour. 'Pachequino' and both Sicilian landraces produced seeds richer in fibre fractions. As regard to oil quality, the oleic acid/linoleic acid was found balanced (about 1) for Turkish landrace, and it decreased for the other genotypes reaching the lowest value for 'Pachequino'. 'Modica' had higher quantity of unsaponifiable matter (UM) in the oil, whereas 'Yori 77' had the maximum concentration of phytosterols (Phy). Policosanol fraction (PC) prevailed in oil of 'Ispica'. Moreover, there was variability in the fatty acids (FAs), Phy and PC compositions with marked differences among the tested genotypes. These results provide information to exploit sesame within agrosystems under Mediterranean to sub-tropical climates, and may be a starting point to activate breeding programs to enhance the crop productivity and grain quality.

INTRODUCTION

Sesame (*Sesamum orientale* L. often called *Sesamum indicum* L.) is an annual plant known to humans since antiquity and almost certainly domesticated in India (Bedigian, 2003). The species has a long cultivation history, but with time it has been neglected, unless by farmers of some developing and emerging countries, mostly in Asia, Africa and to a minor extent in Latin America.

Nowadays, the most important producers of sesame grain remain India, Myanmar, China, Sudan, Uganda, Ethiopia and Nigeria. However, the species can be considered suitable for different farming systems either as a main or second crop, also under low input cropping conditions in line with the requirements of the sustainable agricultural policy of European Union. The estimated world's production of sesame seeds attains 4.21×10^6 Mg on 8.06×10^6 ha, with a yield of 0.52 Mg ha^{-1} and an oil amount of 1.11×10^6 Mg (2008–2012 means) (FAO-STAT Agriculture, 2014).

Sesame seeds, although are much required mainly for edible oil (36–63%) represent an appreciable source of protein (18–28%), carbohydrate (14–16%) and minerals (5–7%), especially calcium and phosphorus, and hence are used all over the world as ingredient in the preparation of various food products (tahini, halva, rolls, crackers, cakes, buns, chips, soup, etc.). Defatted sesame meal is a protein-reach (34–50%) feed with a balanced amino acid composition for farm animals (Weiss, 1983; Ashri, 1989; Bahkali *et al.,* 1998; Elleuch *et al*., 2007).

Most recently, although allergenic reactions have been associated to increasing consumption of foods containing sesame, bioactive constituents having nutraceutical, pharmaceutical, cosmeceutical and ethnobotanical interest have been recognized and hence sesame grain can be considered as a "microcapsule" for health and nutrition as indicated by the famous saying "seed of immortality" (Morris, 2002; Bedigian, 2003; Kanu *et al.,* 2007). The phytochemicals identified in coat and embryo of sesame seed (ethyl protocatechuate, lignans, essential fatty acids, phytosterols, tocopherols, pospholipids, polyphenols, flavonoids, resveratrol, lectins, fiber), offer a wide spectrum of opportunities to promote the development of high-value-added bio-based products in both the food and non-food industry including bioenergy (Hardy, 2002; Kanu *et al*., 2007; Anilakumar *et al*., 2010). This can also help in the implementation of the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) system (Regulation EC 1907 2006) adopted by the European Union. The latter has a consolidated deficit in the lipid sector and in 2011 imported 1.65×10^5 Mg of oilseeds together with 2.84×10^5 Mg of vegetable oils. In the same year, the E.U. countries imported overall 1.30×10^5 Mg of sesame seed and 9.79×10^3 Mg of sesame oil.

In Italy, exclusively limited-scale holders grow sesame in restricted cropping areas of Sicily, giving an amount of product inadequate for the continuously increasing national demand (personal observation). In 2011, Italy imported 6.59×10^3 Mg of sesame seeds and 101 Mg of sesame oil (FAO-STAT Agriculture, 2014). In fact, according to law, margarines and similar products must contain 5% sesame oil to permit detection of adulteration of butter. Moreover, in southern Italian regions, sesame seeds are used on bread and to prepare or garnish traditional cakes.

Anyway, the major international commercial interest for sesame seed remains the lipid matter (over 60% of the global annual consumption), which owing to its peculiar composition could be considered a functional component. Triacylglycerols (TAGs) of sesame oil include mainly oleic acid (34–46%) and linoleic acid (37–48%), together with palmitic acid (8–12%), stearic acid (4–7%) and others minor fatty acids (FAs) (Weiss, 1983; CODEX Stan 210, 1999; Were *et al.,* 2006; Kanu *et al.,* 2007).

According to the Codex Alimentarius (CODEX Stan 210, 1999), the unsaponifiable matter (UM) in sesame oil varies from 0.5 to 2% and contains mostly phytosterols (Phy), although has been reported a strong variability in their concentration (4500–19000 mg kg^{-1}). The prevalent Phy-class is that of 4-desmethyl sterols, represented principally by β-sitosterol (58–62%), campesterol (10–20%), stigmasterol (3–12%) and Δ5-avenasterol (6–8%).

Like other vegetable lipids, sesame oil UM comprises tocopherols (330-1010 mg kg^{-1}), principally as γ-homologue (CODEX Stan 210, 1999), and a fraction of aliphatic alcohols or policosanols (PC). The latter, which derive from waxy components and are known as health promoting compounds for humans (Stuchlík and Žák, 2002), have not been extensively studied in oilseed species including sesame.

It has been known that genetic, environmental and agronomic factors can affect the quantity and composition of the oil produced by a given oilseed crop, but the literature available for sesame seed concerns mainly seed oil content and FAs composition. The geographical origin of genotypes, the indeterminate or determinate growth habit, the position of the capsules within the plant, the degree of seed maturation, and the sowing time can affect the synthesis of FAs and their final proportion in the oil. However, there are little findings on the UM constituents (Baydar *et al.,* 1999; Were *et al.,* 2006).

The information on sesame germplasm collected worldwide is partial due to little research interest. Consequently, a detailed knowledge of the agronomic features and seed composition of available sesame genotypes is essential for safeguarding the existing genetic resources and can help the breeding for adaptability, high yield and product quality (Morris, 2002; Baydar, 2005; Uzun and Çağırgan, 2006; Uzun *et al.,* 2008; Yol and Uzun, 2012). For these reasons, the current study aimed to assess the performance of landraces in comparison with commercial varieties of sesame in a Mediterranean to sub-tropical climatic region of Italy.

MATERIALS AND METHODS

Field experiment

The field trials were conducted during the spring-summer of 2003 and 2004 at Ispica (36°47′N; 14°54′ E; 10 m a.s.l.) a coastal site of south-eastern Sicily (southern Italy).

The soil of the experimental area is classified as Calcixerollic Xerochrepts (S.T. USDA) and it has clay-loam texture, neutral pH (7.3) and satisfactory chemical fertility (organic matter 1.6%, total and active $CaCO_3$ 28.5 and 6.6%, respectively, total N 1.4‰, assimilable-P 25.3 ppm, exchangeable-K 328.9 ppm). According to Costantini *et al.* (2013), the climate of the site is classified as Mediterranean to subtropical, partly semiarid.

Two Italian landraces ‘Ispica’ and ‘Modica’, collected from farmers in the homonymous locality of south-eastern Sicily, were compared with a landrace of Turkish origin and two commercial varieties ‘Pachequino’ and ‘Yori 77’ of sesame.

The experimental field was managed by autumnal ploughing of the soil at 0.25 m depth, harrowing with a disc harrow and fertilizing with 80 kg ha^{-1} of N as urea, 120 kg ha^{-1} of P_2O_5 and 100 kg ha^{-1} of K_2O as superphosphate and potassium sulphate, respectively. An additional 40 kg ha^{-1} of N as ammonium nitrate was supplied at the stage “first flower bud appearance” of the plants. Sowing was performed manually on

30 May and 02 June, respectively in the two years, planning a plant population of 7 plants m^{-2}.

A randomized-block design with three replicates was adopted, whose plot of 25.2 m^2 consisted of 6 rows 6.0 m long 0.7 m apart.

The field was irrigated by means of perforated PVC pipes placed between the rows, starting immediately after sowing to increase the soil moisture up to the field capacity, and thus proceeding until the seed appearance stage, ensuring suitable water conditions based on the plants and soil status (313 and 386 mm, respectively, in the two years). The weed control was performed manually if necessary.

Temperature and rainfall data during the crop cycle were acquired from a station of the Sicilian Agro-meteorological Information Service (SIAS) located near the experimental site.

The phenology of the plants was monitored according to a scale of Zavareha *et al.* (2008) that defines the following stages: emergence (aboveground fully opened cotyledons), first node (first node visible on main stem), first flower (first flower bud visible in the leaf axil), first capsule (at least one flower with a growing capsule greater than 5 mm), seed appearance (at least one flower with a growing capsule and visible seeds filled with semi-transparent matter), visible cotyledons (at least a capsule is in real shape and cotyledons are visible by pressing seeds softly), maturity (at least two capsules of middle parts of main stem capsule bearing zone with seeds showing dark seed line). A given stage was recognised when at least 50% of plants of each plot reached it.

At “first capsule” stage, morphological traits (height, height to the first capsule, number of branches, number of leaves, leaf area by a Li-Cor LI 3100 meter and above ground oven-dry weight at 105°C) were measured on a sample of five plants of each plot. At harvest, seed yield was determined from plants of undisturbed inner area of the plots (1.4 x 5.0 m), whereas samples of five plants were separately collected to determine the yield components (number of capsules per plant, number of seeds per capsule and seed weight).

Chemical analyses

Seed samples of each experimental unit were ground and used to analyse crude lipid content (%) by Soxhlet method (petroleum ether 40-60°C). FAs of TAGs (% of the total concentration), UM (%) and total Phy and PC fractions (mg kg^{-1} of crude oil) and their individual compounds (% of the total concentration), were analysed in duplicate according to the E.U. official methods (European Economic Commission, 2003).

The instruments (GC systems) and the analytical procedures and conditions (stationary phase, carrier gas, thermal regime, etc.) were described in detail in Anastasi *et al.* (2000; 2010). The residual defatted flour (DF) was analysed for nitrogen content by Kjeldahl method and crude protein content (%) was calculated (N x 6.25). Acid detergent fibre (ADF), neutral detergent fibre (NDF) and acid detergent lignin (ADL) fibre fractions (%) were determined with a fiber analyser (Fibertec System, M, Tecator, Hoganas, Sweden) according to the Van Soest procedure (Van Soest *et al.,* 1991).

Statistical analysis

After the normality test (Bartlett), ANOVA was applied using CoStat 6.003 version (CoHort Software 2001), setting the significance threshold at $P \leq 0.05$. Data were analysed first for a single year, and because of homogeneity of the errors mean squares was found a combined analysis between genotypes and years was performed, and means were compared by the *F*-protected L.S.D. test (DF = 28). As for all response variables there was not significance of interaction between genotype and year factors, the means across two years were presented.

Correlation analysis between response variables ($P\leq0.05$, $P\leq0.01$ and $P\leq0.001$) was performed through the years, genotypes and replications (DF = 28).

RESULTS

Weather

The time course of temperature and rainfall during the experiment reflect the average weather conditions of the Mediterranean to sub-tropical partly semiarid climatic regions of southern Italy (Figure 1).

Thermal regime showed an increase from late May (crop establishment period) to mid-August (grain filling period), and then a gradual decrease. There was an average difference of 2.3 and 1.9 °C in the maximum and minimum temperature, respectively, between the two cropping seasons.

Less rainfall occurred from late May to mid-September in the second year (66 mm) compared to the first one (223 mm), although the late rainfall fell in September (152 and 52 mm, respectively) was not useful for the crop. This rainfall regime justifies the different seasonal irrigation volumes supplied to the crop.

FIG. 1

Cropping cycle and morphological traits

The duration of the cropping cycle, which was 122 days on average, significantly differed among the cultivars (Figure 2). In particular, the landraces 'Ispica' and 'Modica' and the Turkish genotype, who were similarly earliest, ended the cycle, on average, 17 days before either 'Pachequino' and 'Yori 77', which had similar length of the cycle.

This result was essentially due to the earliness of flowering (1^{st} node to 1^{st} flower phase) and fruit setting (1^{st} flower to 1^{st} capsule phase) of the Sicilian and Turkish landraces compared to the two commercial varieties (on average, −18 and −12 days difference, respectively for the two phases). Hence, the Sicilian and the Turkish landraces significantly prolonged the fruit setting (1^{st} capsule to seed appearance) as well as the grain filling (visible cotyledons to maturity) in comparison to the other two genotypes (on average, +20 and +5 days difference, respectively for the two phases).

FIG. 2

The data of morphological traits and dry biomass of sesame genotypes are summarised in Table 1.

The plants of 'Modica' and Turkish landraces were significantly taller in comparison to the other cultivars, whereas the height of the insertion of lower capsule was greater for both Sicilian landraces. The latter, however, also had a higher number of branches per plant.

At the crucial reproductive stage, some slight difference in terms of leaf number and leaf area per plant emerged in favour of the landraces, and 'Modica' and to a minor extend 'Ispica' reached also greater aboveground dry weight per plant compared to the other genotypes.

Productive traits

Grain yield and yield-contributing traits are presented in Table 2. ANOVA highlighted a significant productive advantage for ‘Pachequino’ followed by ‘Modica’ in comparison to the other cultivars. The productive performance of the above two genotypes was significantly affected by the number of capsules per plant (overall, 227 and 201, respectively, against 155, on average, for the other cultivars).

Conversely, the values of the other yield components were less variable and did not differ among the cultivars.

Grain quality traits

Figure 3 shows the changes in the seed lipid and protein content of DF (A), and the oil and protein yields (B) of the tested sesame cultivars. Turkish and ‘Ispica’ landraces produced grain with a significantly higher oil content (55.5 %, on average), whereas seeds were less rich in lipid in ‘Pachequino’ and ‘Modica’ (51.6 %, on average).

Turkish landrace provided a greater oil yield (1.8 and 1.6 Mg ha^{-1}, respectively), due to the higher seed yield. This cultivar also reached highest protein content of the DF (45.4%), which was similar to that of ‘Yori 77’ (44.0 %), although the latter value was undifferentiated from those of ‘Ispica’ and ‘Pachequino’ (43.0%, on average); the second one, as a result of the greater seed yield, also provided the highest protein yield (1.5 Mg ha^{-1}). There was a positive correlation between the lipid and the protein concentrations (r=0.464, $P\leq$0.01) in sesame cultivars.

FIG. 3

Figure 4 shows the changes of the fibre fractions in the seeds of the sesame genotypes. The NDF and ADF prevailed in both ‘Modica’ and ‘Pachequino’ seeds (18.7

and 11.5%, on average, for each fraction, respectively), whereas ADL was higher in the seeds of ‘Ispica’ (3.6%). NDF was found inversely correlated with seed oil content (r= −0.459, P≤0.05) as well as with protein content of defatted meal (r= −0.659, P≤0.001). The latter was also negatively associated with ADL (r= −0.424, P≤0.01).

FIG. 4

The concentration of the main FAs in the sesame TAGs is shown in Table 3. Regardless of the genotypes, the two Saturated fatty acids (SAFAs), palmitic (C16:0) and stearic (C18:0), reached a whole concentration of 15%, whereas those of monounsaturated and diunsaturated FAs, oleic (C18:1) and linoleic (C18:2), respectively, were overall equal to 84 %. Between the saturated FAs, the concentration of palmitic acid always prevailed compared to that of stearic acid with restricted variations among genotypes for the C18:0 and with an advantage for ‘Yori 77’ concerning the C16:0. Within the two prevailing unsaturated FAs C18:1 and C18:2, the proportion of the second one was, on average, always greater than that of the first one, but with a significant advantage for the C18:2 in ‘Pachequino’ oil and for the C18:1 in the oil of Turkish genotype.

The correlations between individual FAs showed that the percentage of C16:0 is negatively associated with that of C18:0 and with that of C18:1 (r= −0.488, P≤0.01 and r= −0.749, P≤0.001, respectively), whereas the percentage of the latter is inversely associated with that of C18:2 (r= −0.667, P≤0.001).

The amount of UM and total Phy as well as the proportion of the main sterols of the oil in the studied genotypes are reported in Table 4. In particular, the greater quantity of UM was observed in the oil of ‘Modica’, whereas ‘Yori 77’ oil had the lesser one. In contrast, there was a higher concentration of Phy in the ‘Yori 77’ oil compared to those of the other cultivars. Among the four main individual Phy belonging to desmethylsterols class, β-sitosterol prevailed in the oil all the genotypes compared to the other compounds followed by campesterol, but while the concentration of the first one was significantly higher in the oil of the two commercial varieties, the second one was in a greater amount in the 'Ispica' oil. Stigmasterol and Δ5-avenasterol was significantly higher in the oils of 'Pachequino' and 'Modica', respectively.

The correlation analysis between individual Phy evidenced that the proportion of campesterol in the oil was negatively associated with the percentage of both stigmasterol and β-sitosterol ($r= -0.646$ and $r= -0.688$, $P \leq 0.001$, respectively), whereas it was positively correlated with the percentage of Δ5-avenasterol. β-Sitosterol percentage was associated positively with stigmasterol percentage and negatively with Δ5-avenasterol percentage of the oil ($r= 0.564$, $P \leq 0.01$ and $r= -0.975$, $P \leq 0.001$, respectively).

Total PC of the oil and the major compounds revealed significant differences between the cultivars (Table 5). In particular, the oil of 'Ispica' had higher quantity of PC compared to that of the other genotypes. This fraction of unsaponifiable was found to be positively correlated with seed oil content ($r= 0.763$, $P \leq 0.001$).

As regards to PC composition, the percentage of docosanol (C22-ol) was lower for 'Pachequino' oil, which instead had higher tetracosanol (C24-ol) percentage. The hexacosanol (C26-ol) percentage was significantly higher in 'Ispica' oil, which also had greater octacosanol (C28-ol) proportion together with 'Paquechino' oil.

The correlations between the individual PC of the oil highlighted that the proportion of C22-ol were positively associated with that of C24-ol ($r= 0.751$, $P \leq 0.001$) and negatively correlated with those of C26-ol and C28-ol ($r= -0.875$ and r= -0.883,

$P \leq 0.001$, respectively). Moreover, negative associations of C24-ol percentage with both C26-ol and C28-ol proportions ($r = -0.582$, $P \leq 0.001$ and $r = -0.465$, $P \leq 0.01$, respectively) were observed, whereas C26-ol and C28-ol contents were positively correlated ($r = -0.955$, $P \leq 0.001$).

DISCUSSION

Sesame cultivars revealed different biological and morphological *habitus*. Overall, the plants of the landraces were earlier in flowering and fruiting, taller, with greater height of insertion of lower capsule, and tended to achieve greater leaf development and aboveground dry weight accumulation in comparison to the commercial varieties. This is in agreement with the results of Yol and Uzun (2012). The earliness is a key biological trait for semiarid environments of southern Italy, because it allows the shortening of the cropping cycle without penalizing the grain filling and maturation, reducing the water use of sesame and making the soil soon available for a new crop.

The branching habit of the genotypes varied from moderate in 'Pachequino' and Turkish (3) to high in the remaining genotypes (≥4), which can be considered bushy type. In sesame, the branching habit is a varietal attribute variously affected by environmental and growing conditions with the branches number ranging from 0 to 20 (Weiss, 1983). Therefore, the low plant population adopted in this experiment has certainly helped the expression of this trait. Anyway, the morphological *habitus* of the tested genotypes can be considered quite suitable for crop management, since a plant type within 150-160 cm in height, not too branching and with capsules inserted not closed to the ground and not more than 70 cm, is considered ideal to non-lodging, high-yielding and mechanical harvesting. For the latter aspect, however, the major difficult remains the uneven ripening of the capsules due to the indeterminate growth habit, which is typical of the most currently available cultivars, including those considered in the present study (Baydar, 2005; Uzun and Çağırgan ,2006).

The main component involved in yielding ability of sesame was the number of capsules per plant as reported by Baydar (2005). This trait significantly affected the performance of the most productive cultivars ‘Pachequino’ and ‘Modica’, although the advantage in terms of fruiting capacity was not for either genotypes a direct consequence of branching aptitude, as the first one produced many capsules also in the main stem. The other yield components were not relevant to the different productive capacity of the studied cultivars, in agreement with Yol and Uzun (2012).

As regards to the grain quality, the average oil content (53%) was in the range reported in the literature for sesame (36-63%), and was higher than the average values found by Were et al. (2006) in 30 accessions of the species (40.8%). Moreover, agreed with the findings of Weiss (1983) and Uzun *et al.* (2008) the highest level was found in Turkish landrace, although it did not reach 60% as these authors reported. In the DF of the same genotype was found the greatest protein content slightly above 45%, although other cultivars as ‘Yori 77’ ‘Ispica’ and ‘Pachequino’ reached similar level.

The observed positive correlation between the lipid and the protein, suggests that the synthesis of these main reserve constituents is not conflicting in sesame seeds according to Chung *et al.* (1995). On the other hand, either oil and protein concentration were found negatively correlated with some fibre fractions. Anyway, the richness in crude protein and the proportions of ADF, NDF, ADL, which is usually associated to a low content of anti-nutritional factors, confirms that sesame DF can be alternatively used to soybean DF in specific programs of animal feeding (Barreyro *et al.,* 2014).

As expected in accordance to the literature (Weiss, 1983; Kanu *et al.,* 2007), the concentration of the main four FAs accounted for 98-99% in the profile of sesame TAGs, of which almost 85 % was represented by unsaturated compounds oleic acid and linoleic acid, with a prevalence of the second one in all the cultivars. However, the C18:1/C18:2 of the oil, which was equal to 0.97 in Turkish landrace, decreased in the two Sicilian landraces (0.90 and 0.86 for 'Modica' and 'Ispica', respectively) and even more in both commercial varieties (0.83 and 0.78 for 'Yori 77' and 'Pachequino', respectively). The predominance of the linoleic acid in sesame oil is well documented in the literature, because there is a close genetic control of the basic FAs composition. However, as in other oilseed species for a given genotype of sesame, fluctuations in environmental and growing conditions can modify the concentration of the individual compound (Were *et al.,* 2006; Uzun *et al.,* 2008; Anastasi *et al.,* 2010).

Concerning the saturated FAs of the oil, Were *et al.* (2006) observed a lower range in stearic acid among 30 sesame accessions, which was confirmed by our results.

The observed relationships between individual FAs also agree with the findings of the above-mentioned authors and a number of reports on other oilseed crops such as sunflower (Anastasi *et al.,* 2010). This confirms what has been widely reported in the literature on the role played by the elongation and desaturation during the FAs synthesis in regulating the proportions of these compounds in TAGs.

The other common FAs of sesame oils listed in the CODEX Stan 210 (1999): myristic, palmitoleic, heptadecanoic, heptadecenoic, arachic, linolenic, behenic, eicosenoic, erucic were not detectable or present in very low amount (data not shown).

The categories saturated fatty acids (SFAs), monounsaturated fatty acids (MUFAs) and poliunsaturated fatty acids (PUFAs) were also calculated including the complete FAs profile (data not shown). It is noteworthy, mainly from a nutritional point of view (Kanu *et al.,* 2007), that the oil of Turkish landrace had lower amount of both SFAs and PUFAs, and greater percentage of MUFAs (14.4, 43.4 and 42.2%, respectively), whereas the quantity of PUFAs prevailed in the 'Pachequino' oil (47.4%) as compared to the other genotypes. The two Sicilian landraces provided oil with similar amount SFAs, MUFAs and PUFAs (15.4, 39.6 and 44.9%, on average).

On the other hand, Ahmad *et al.* (2010) highlighted that the performance of engine fueling with methyl esters prepared from sesame oil (biodiesel) or its blends (5, 10 and 20%) are similar compared to mineral diesel and satisfy the EU standard EN14214. In this view, a further advantage compared to the other lipid raw materials is due to the presence of lignans (sesamin and sesamolin) and other antioxidants compounds such as tocopherols and squalene that enhance the stability of the sesame oil, although its high degree of unsaturation.

The variation of UM and total Phy, and the sterol composition of the oil in the studied genotypes agreed with literature (Mohamed and Awatif, 1998; CODEX Stan 210, 1999). However, it is of particular interest to point out that UM was found in highest quantity (almost 2%) in the oil of 'Modica' landrace, whereas, oil of 'Yori 77' variety was the richest (over 5500 mg kg^{-1}) in Phy, with a prevalence of β-sitosterol. Moreover, the concentration of Δ5-avenasterol was strongly predominant in the oil of the two Sicilian landraces with values outside the upper limit indicated in the CODEX Stan 210 (1999), but coherent to those found by Mohamed and Awatif (1998). The latter reported that the above compound belonging to Δ-24,28 ethylidene sterols has an antipolymerisation effect that could protect oils from oxidation.

The correlations between individual Phy were in disagreement with those reported by Tir *et al.* (2012), except that between campesterol and Δ5-avenasterol concentrations. However, the results may be influenced by the different solvents and conditions used for the oil extraction.

The complete profile of the oil Phy fraction (cholesterol, 24-methilen cholesterol, campestanol, Δ7-campesterol, Δ5,23-stigmastadienol, clerosterol, sitostanol, Δ5-avenasterol, Δ5,24-stigmastadienol, Δ7-stigmastenol, Δ7-avenasterol and others) (data not shown) were in agreement to that reported for sesame (CODEX Stan 210, 1999).

Regarding the amount of total PC of the oil, which is a poorly studied fraction of vegetable oils, 'Ispica' was the best genotype. Among the individual PC, C22-ol prevails usually on the other compounds in the oil of all the tested cultivars, although not by much. In fact, the oil of Sicilian landrace 'Ispica' contains higher proportion of C26-ol, evidencing a peculiar PC composition. PC are a mixture of long-chain aliphatic alcohols (also called fatty alcohols) known as components of waxy material in various plants and destined to gain importance owing to the beneficial physiological effects.

Lately these phytochemicals are commercialized as natural dietary alternative to statin in the control of cholesterol level in the blood (Stuchlík and Žák, 2002). These bioactive metabolites, mainly C18 to C36 terms, are currently derived from tall oil (major terms C22-ol and C24-ol) and sugarcane (major term C28-ol), but there are other potential raw materials such as rice bran (major terms C28-ol, C30-ol and C32-ol), grain sorghum (major term C28-ol and C30-ol) and some oilseed species. Anastasi *et al.* (2010) reported a prevalence of C24-ol followed in decreasing order by C26-ol, C22-ol and C28-ol terms in sunflower oil, whereas Adhikari *et al.* (2006) found that in perilla seeds there were mostly C28-ol and then C26-ol and C30-ol. The proportions of individual PC were found variously associated, but only the positive correlation between C26-ol and C28-ol contents has been previously reported for another oil crop (Kim *et al.,* 2012). As soon as more data on PC composition of sesame oil will become available, may be useful for understanding the relationships between these important minor compounds.

No appreciable variations in relation to the genotypes emerged in the proportions of other detectable PC of oil, tricosanol (C23-ol), pentacosanol (C25-ol) and heptacosanol (C27-ol) (data not shown).

CONCLUSION

This study highlights that the tested sesame cultivars performed well in Mediterranean to sub-tropical partly semiarid environment, each showing peculiar and valuable characteristics. Particularly, among the agronomic traits that have distinguished the Turkish and both Sicilian landraces can be mentioned the earliness and the greater height of insertion of first capsule, which could facilitate mechanical harvesting. In contrast, the variety ‘Pachequino’, although most later, demonstrated better productive ability due to the greatest capsules produced. In terms of grain quality, Turkish and ‘Ispica’ landraces and ‘Yori 77’ variety performed better in terms of seed lipid content and protein content of DF. The grain of ‘Pachequino’ variety and both Sicilian landraces was richer in fibre fractions. Turkish landrace provided oil with balanced (about 1) C18:1/C18:2, which is a peculiarity for sesame oil, whereas this unsaturation ratio decreased in the oil of other genotypes reaching the lowest level for ‘Pachequino’.

The UM was found in higher amount in the oil of the ‘Modica’ landrace, whereas it was the lowest in that of ‘Yori 77’ variety, which, instead, had the maximum concentration of Phy with a predominance of β-sitosterol. In contrast, PC prevailed in oil of ‘Ispica’ landrace, which had also a major concentration in both C26 and C28 terms. The findings presented offer interesting information to valorise sesame in farming systems of southern Italy and other similar Mediterranean to subtropical environments worldwide, and can be useful to start a breeding activity to enhance the crop productivity and grain quality.

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Tables captions

Table 1. Morphological traits and dry biomass of sesame (2-year average). Means followed by the same letter or letters within a column do not differ significantly ($P \leq 0.05$ F-protected L.S.D.).

Table 2. Productive traits of sesame (2-year average). Means followed by the same letter or letters within a column do not differ significantly ($P \leq 0.05$ F-protected L.S.D.).[†]Not significant.

Table 3. Main fatty acids of sesame oil (2-year average). Means followed by the same letter or letters within a column do not differ significantly ($P \leq 0.05$ F-protected L.S.D.).

Table 4. Unsaponifiable matter, total phytosterols and main sterols of sesame oil (2-year average). Means followed by the same letter or letters within a column do not differ significantly ($P \leq 0.05$ F-protected L.S.D.).

Table 5. Total policosanols and main policosanols of sesame oil (2-year average). Means followed by the same letter within a column do not differ significantly ($P \leq 0.05$ F-protected L.S.D.).

Figure captions

Figure 1. Time course of maximum and minimum air temperature (10-days means), and rainfall (10-days totals) from May to September in 2003 and 2004 at the experimental site.

Figure 2. Crop cycle and its phases of sesame genotypes (S, sowing – E, emergence – 1^{st} N, first node – 1^{st} F, first flower – 1^{st} C, first capsule – SA, seed appearance – VC, visible cotyledons - M, maturity). Different letters within each phase and whole cycle (inside and outside the stacked bars, respectively) indicate significant differences between the 2-year-means ($P \leq 0.05$ F-protected L.S.D.).

Figure 3. Seed oil content and protein content of defatted flour (A), oil and protein yields (B) of sesame genotypes. Different letters above the bars within each response variable indicate significant differences between the 2-year-means ($P \leq 0.05$ F-protected L.S.D.).

Figure 4. Seed fibre fractions (NDF, ADF, ADL) of sesame genotypes. Different letters above the bars within each response variable, indicate significant differences between the 2-year-means ($P \leq 0.05$ F-protected L.S.D.).

Table 1

Cultivars	Plant height (m)	Height to 1st capsule (m)	Branches (n plant^{-1})	Leaf (n plant^{-1})	Leaf area (m^2 plant^{-1})	Dry biomass (g plant^{-1})
Pachequino	0.7 c	0.42 c	2.7 c	65.0 bc	30.0 ab	50.0 c
Yori 77	0.7 c	0.41 c	4.7 b	53.3 c	25.1 b	37.9 d
Turkish	1.5 a	0.47 b	3.0 c	62.8 bc	28.3 ab	43.1 cd
Ispica	1.4 b	0.54 a	6.4 a	74.7 ab	33.8 a	62.1 b
Modica	1.6 a	0.56 a	6.6 a	78.7 a	33.6 a	74.1 a
Mean	1.2	0.48	4.7	66.9	30.2	53.4
S.E.	0.2	0.12	0.6	4.6	2.2	2.8
C.V. (%)	4.8	6.21	24.5	15.0	16.5	12.1

Table 2

Cultivars	Capsules (n $plant^{-1}$)		Seeds[a] (n $capsule^{-1}$)	Seed weight[a] (mg)	Seed yield (t ha^{-1})
	Stem	Branches			
Pachequino	101.7 a	125.0 a	63.8	3.3	3.5 a
Yori 77	60.7 cd	62.8 b	64.2	3.3	1.9 d
Turkish	47.8 d	107.5 a	68.0	3.5	2.6 c
Ispica	66.5 c	121.0 a	65.0	3.1	2.5 c
Modica	82.2 b	118.8 a	64.5	3.2	3.0 b
Mean	71.8	107.0	65.1	3.3	2.7
S.E.	5.3	7.0	3.1	0.1	0.1
C.V. (%)	15.3	15.8	11.2	8.3	9.9

Table 3

Cultivars	Palmitic (%)	Stearic (%)	Oleic (%)	Linoleic (%)
Pachequino	10.29 b	4.43 c	36.82 d	47.09 a
Yori 77	13.51 a	4.65 bc	36.40 d	44.12 c
Turkish	8.74 c	4.90 ac	41.76 a	43.15 d
Ispica	9.25 c	5.38 a	38.78 c	45.15 b
Modica	9.34 c	5.23 ab	39.82 b	44.10 c
Mean	10.22	4.91	38.71	44.72
S.E.	0.20	0.20	0.26	0.21
C.V. (%)	4.94	10.37	1.64	1.14

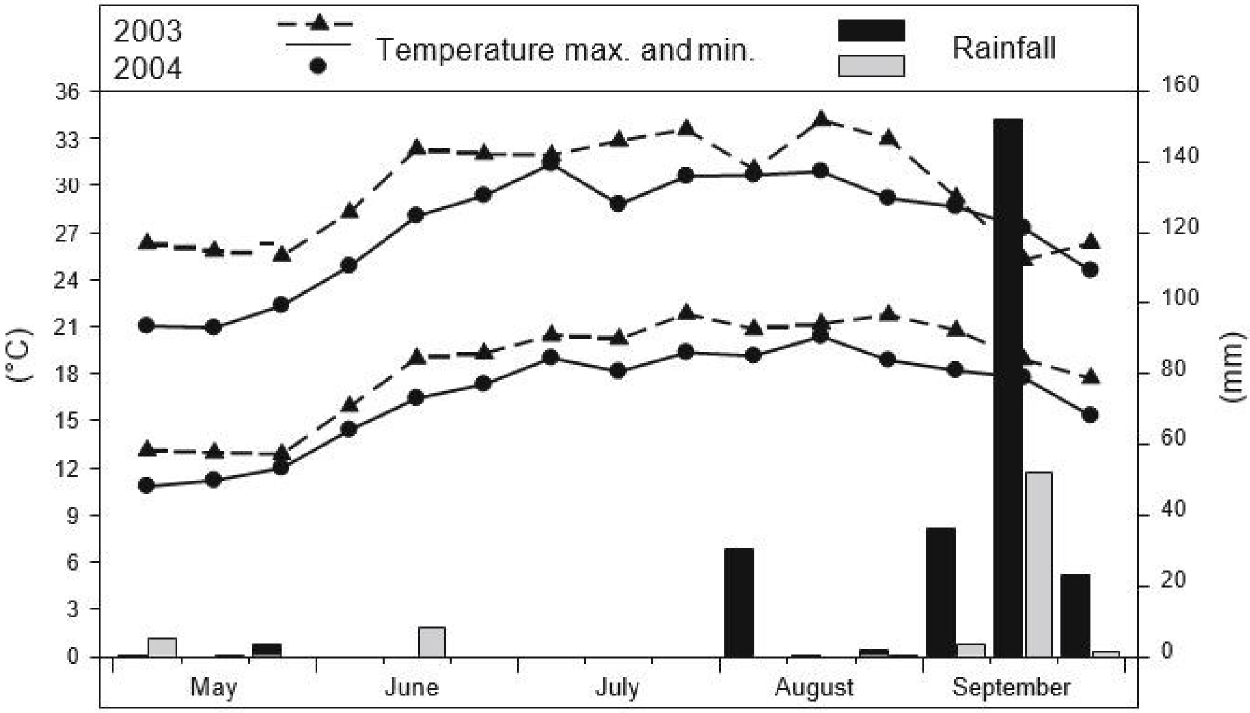
Table 4

Pachequino	1.72 b	4933.67 c	17.72 cd	8.84 a	64.59 a	4.99 d
Yori 77	1.35 c	5532.83 a	17.56 d	8.12 b	64.56 a	5.73 cd
Turkish	1.71 b	4707.67 d	18.61 b	6.68 c	63.54 b	5.80 c
Ispica	1.82 b	5115.00 bc	20.29 a	6.66 c	53.67 d	12.11 b
Modica	1.98 a	5301.83 b	18.20 bc	6.95 c	54.84 c	13.28 a
Mean	1.71	5118.20	18.48	7.45	60.24	8.38
S.E.	0.05	78.23	0.16	0.19	0.34	0.26
C.V. (%)	7.21	3.22	2.19	5.92	1.17	7.46

Table 5

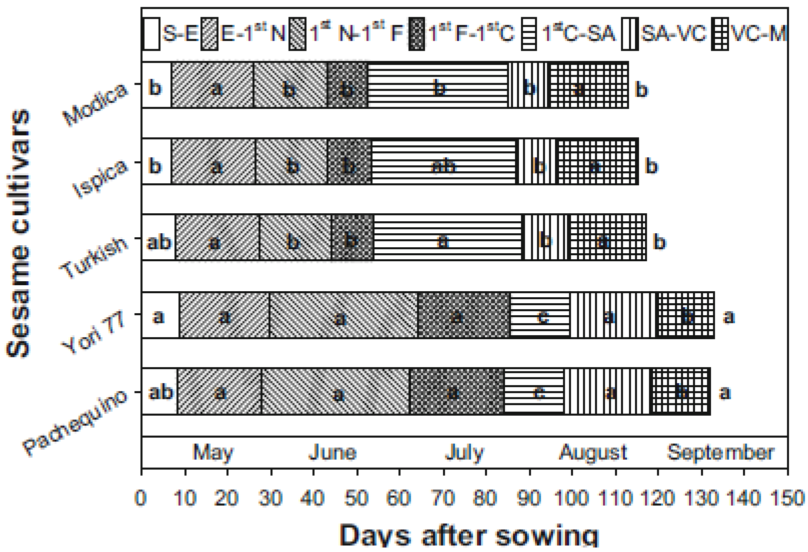
Cultivars	Policosanols (mg kg^{-1})	Docosanol (%)	Tetracosanol (%)	Hexacosanol (%)	Octacosanol (%)
Pachequino	125.80 e	27.29 d	22.23 a	23.93 b	21.71 a
Yori 77	162.67 c	30.28 b	21.25 c	18.49 c	15.24 c
Turkish	185.83 b	28.15 c	18.37 d	17.49 d	16.29 b
Ispica	205.83 a	23.07 e	13.15 e	26.64 a	21.62 a
Modica	130.00 d	35.12 a	21.82 b	15.86 e	12.90 d
Mean	162.03	28.78	19.36	20.48	17.55
S.E.	1.16	0.05	0.06	0.05	0.06
C.V. (%)	1.72	0.43	0.76	0.57	0.76

Fig. 1



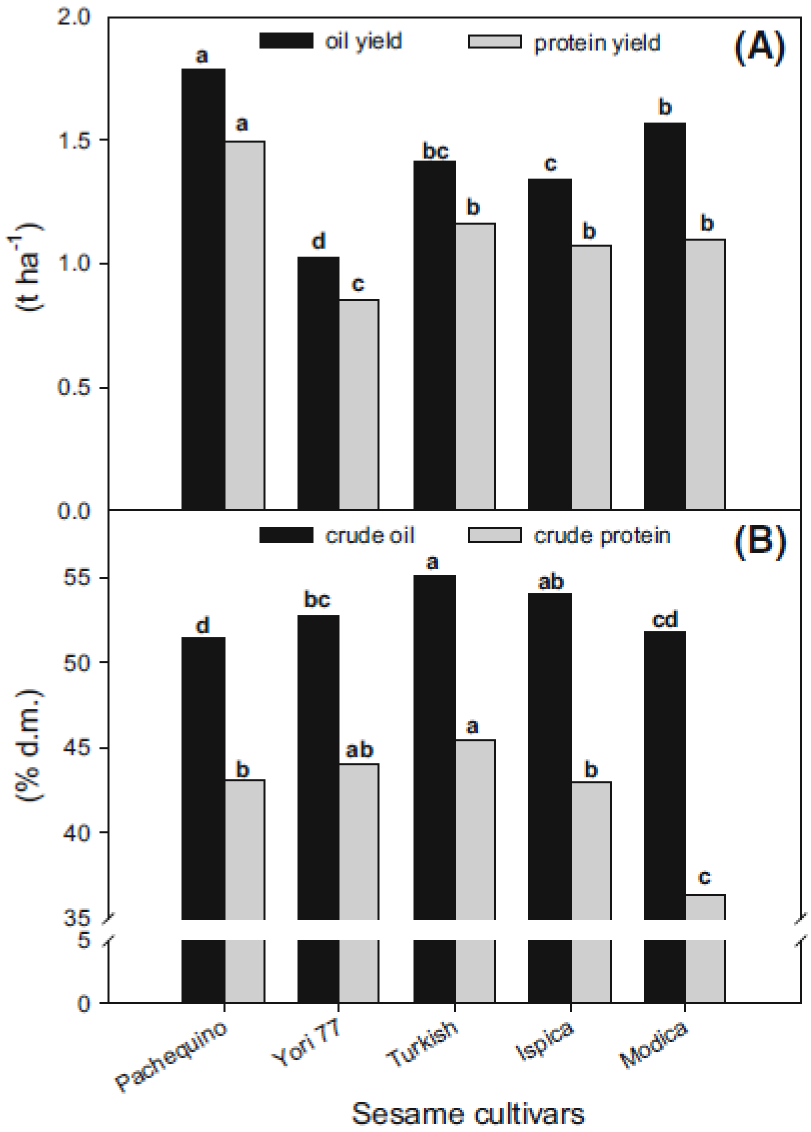
2003
2004
Temperature max. and min.
Rainfall
36
33
30
27
24
21
18
15
12
9
6
3
0
(°C)
160
140
120
100
80
60
40
20
0
(mm)
May
June
July
August
September

Fig. 2



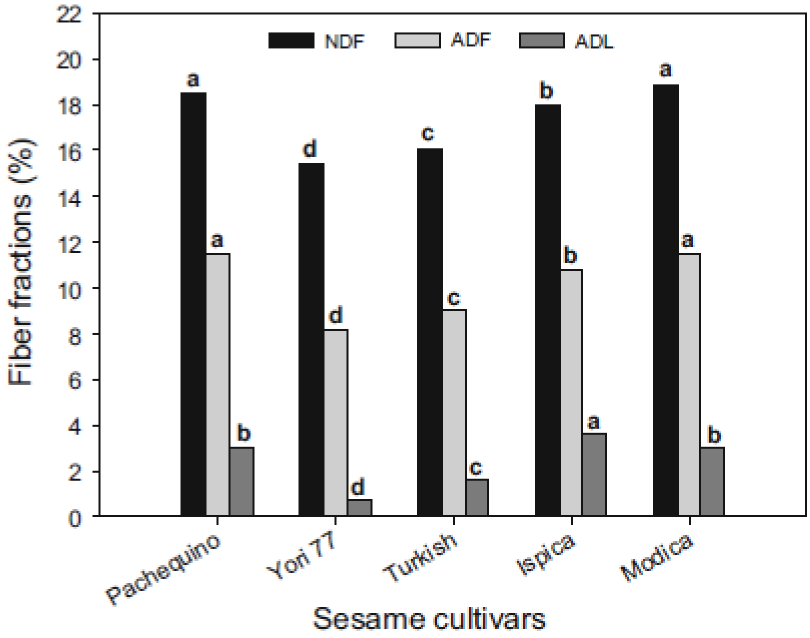
S-E
E-1st N
1st N-1st F
1st F-1st C
1st C-SA
SA-VC
VC-M
Sesame cultivars
Modica
Ispica
Turkish
Yori 77
Pachequino
May
June
July
August
September
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150
Days after sowing

Fig. 3



2.0
1.5
1.0
0.5
0.0
(t ha^-1)
oil yield
protein yield
(A)
a
a
d
c
bc
b
c
b
b
b
crude oil
crude protein
(B)
55
50
45
40
35
5
0
(% d.m.)
d
b
bc
ab
a
a
ab
b
cd
c
Pachequino
Yori 77
Turkish
Ispica
Modica
Sesame cultivars

Fig. 4



NDF
ADF
ADL
Fiber fractions (%)
22
20
18
16
14
12
10
8
6
4
2
0
a
a
b
d
d
d
c
c
c
b
b
a
a
a
b
Pachequino
Yori 77
Turkish
Ispica
Modica
Sesame cultivars