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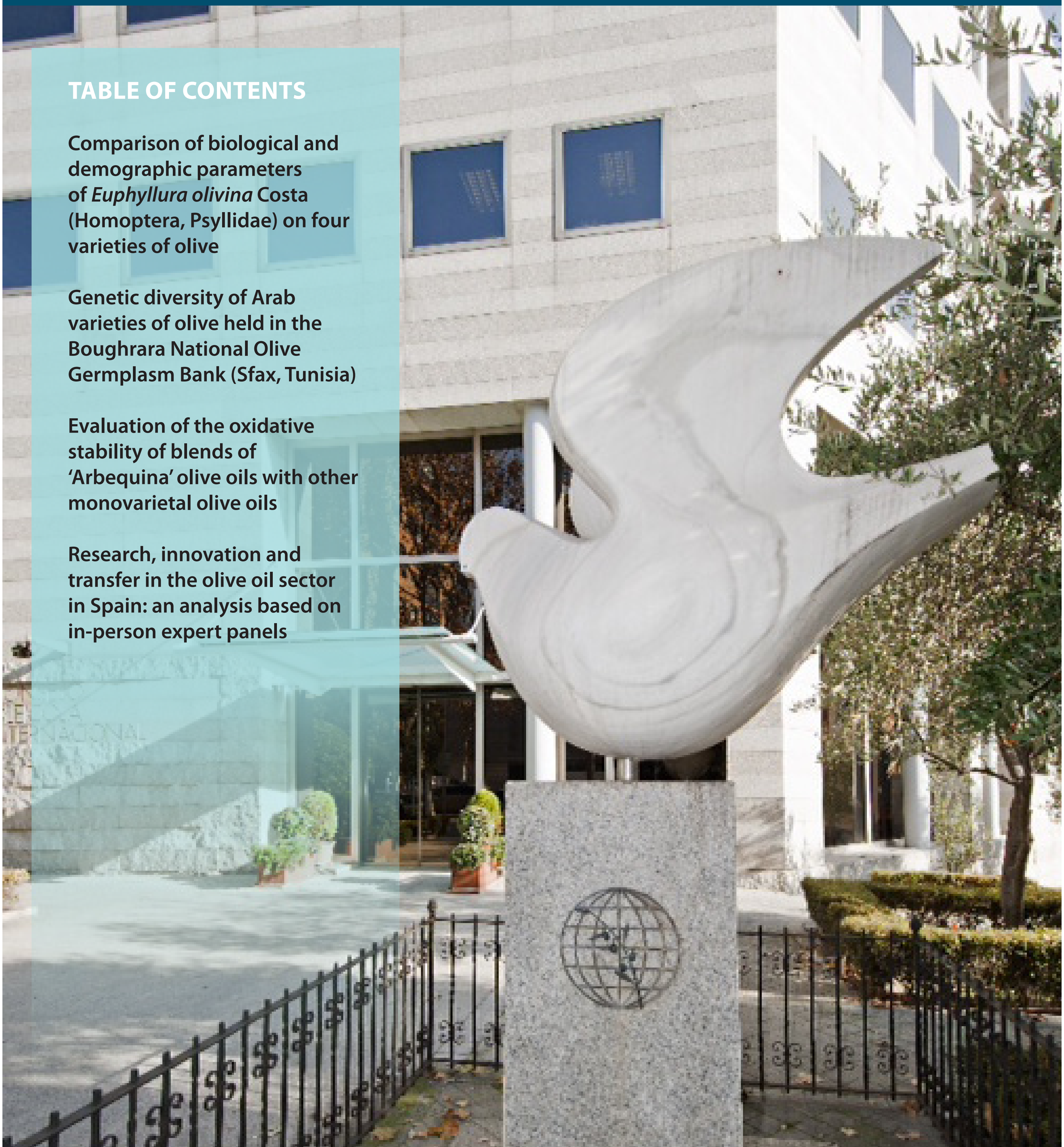

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Comparison of biological and demographic parameters of *Euphyllura olivina* Costa (Homoptera, Psyllidae) on four varieties of olive

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Abstract

The olive tree (*Olea europaea* L.) is a crop of economic importance in Morocco; however, olive production is hampered by pests that cause significant harvest losses. Olive psyllid (*Euphyllura olivina* Costa) causes severe damage in Mediterranean olive orchards. Its control is mainly based on the use of synthetic pesticides, which affect the environment and human health and are also responsible for the resurgence of secondary pests and the development of resistant strains.

Alternative pest control methods incorporating varietal resistance could be promising in the context of sustainable development. Biological and demographic parameters were assessed on four varieties of olive ('Picholine marocaine', 'Haouzia', 'Arbequina', 'Manzanilla') under cover conditions in order to evaluate the response to olive psyllid. Parameter values varied according to variety. Adult female lifespan (48.40±9.21days) was longer, fecundity (877.0±265.63 eggs/2 females) and success rate (9.87%) were higher and mortality rate was lower on 'Haouzia' (72.65±5.41%) than on the other varieties. Age-specific fecundity (*mx*) was 62 females/female of each age on 'Haouzia' and 29 on 'Picholine marocaine'. Net reproduction rate (R_0) was higher on 'Haouzia' (24.0±6.35 females/generation) than on 'Picholine marocaine' (12.3±3.77 females/generation). Intrinsic rate of increase (r_m) was maximum on 'Haouzia' (0.05±00 female/female/day) and minimum on 'Picholine marocaine' (0.04±00 female/female/day); finite rate of increase (λ) was 1.05±00 female/female/day and 1.04±0.00 female/female/day on 'Haouzia' and 'Picholine marocaine', respectively. Cluster analysis of the psyllid parameters studied on the four varieties showed that 'Picholine marocaine' was less conducive to the development of insect populations.

Keywords:

Olea europea, *Euphyllura olivina*, biological parameters, demographic parameters, varietal resistance.

Résumé

L'olivier (*Olea europaea* L.) est une culture économiquement importante au Maroc. Cependant, la production d'olives est entravée par des ravageurs causant des pertes importantes de récolte. Le psylle de l'olivier (*Euphyllura olivina* Costa) cause d'importants dégâts dans le bassin Méditerranéen. Le contrôle de ce ravageur est essentiellement basé sur l'utilisation des pesticides de synthèse. Ces derniers affectent l'environnement, les organismes non ciblés et la santé humaine ; ils sont aussi à l'origine de la résurgence des ravageurs secondaires et du développement des souches résistantes. Des mesures alternatives de protection, dont la résistance variétale, peuvent être prometteuses dans un contexte de développement durable. Pour évaluer la réponse de quatre variétés d'olivier (*Picholine marocaine*, *Haouzia*, *Arbéquine*, *Manzanille*) aux attaques du psylle, des paramètres biologiques et démographiques du ravageur ont été déterminés sur celles-ci sous abri. Les valeurs des paramètres mesurés varient selon la variété considérée : la longévité des adultes femelles la plus longue a été observée sur *Haouzia* (48,40±9,21 jours), avec

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une fécondité moyenne maximale de 877,0±265,63 œufs/2 femelles, un taux minimal de mortalité larvaire (72,65±5,41 %) et le taux de succès le plus élevé (9,87 %). La fécondité selon l'âge des femelles sexuellement matures (*mx*) est de 62 femelles/jour sur Haouzia et de 29 femelles/jour sur *Picholine marocaine*. Le taux net de reproduction (R_0) le plus élevé a été observé sur *Haouzia* (24.0±6,35) et le plus faible sur *Picholine marocaine* (12.3±3,77 femelle/génération). Le taux intrinsèque d'accroissement (r_m) maximum a été enregistré sur *Haouzia* (0,05±00 femelle/femelle/jour) et le minimum sur *Picholine marocaine* (0,04±00 femelle/femelle/jour), tout comme le taux limite d'accroissement (λ), avec respectivement 1,05±00 et 1,04±0,00 femelle/femelle/jour. L'analyse typologique des paramètres étudiés d'*E. olivina* sur les quatre variétés d'olivier montre que la *Picholine marocaine* est la moins favorable au développement de la population d'*E. olivina*.

Mots clés

Olea europaea, Euphyllura olivina, paramètres biologiques, paramètres démographiques, résistance variétale.

Introduction

Olive psyllid, *Euphyllura olivina* Costa (Homoptera, Psyllidae), is a piercing-sucking insect at both the nymphal and adult stages that causes considerable damage to olive orchards in the Mediterranean region (Loginova, 1972; 1976; Chermiti, 1983; Sekkat, 2001; Ksantini *et al*., 2002; Seljak, 2006; Cotes *et al.* 2007; Burckhardt, 2009). It has also been reported in India (Mathur, 1975), Iran (Farahbakhch and Moini, 1975), the United Kingdom, Germany and the United States (California) (Burckhardt and Hodkinson, 1985; Burckhardt, 2009; Malumphy, 2011).

The insect has seven life stages: egg, five nymphal instars and adult (Arambourg, 1964; Hodkinson, 1974). Infected trees can be easily identified from the pale white wax masses surrounding the nymphs (Chermiti, 1983). The adults are omnipresent and the females enter winter and summer ovarian diapause in the hottest months (temperature ≥35 °C) (Ksantini, 2003). The insect is particularly harmful at the nymphal instar stages when it attacks growing plant organs (young shoots and flower clusters); it punctures part of the sap using the stylets inserted in its rostrum and so alters the normal development of the plant organ on which it is feeding, leading to flower sterility (Jardak *et al*., 1985) and fruit and inflorescence drop (Chermiti, 1983). The nymphs secrete a cotton-like mass and honeydew that favours the establishment of the ectoparasitic fungus *Capnodium oleaginum,* which alters tree photosynthesis and lowers tree production (Arambourg and Chermiti, 1986; Chermiti, 1989; Jarraya, 2003). The economic tolerance threshold is around 2.5 to 3 nymphs per 100 flower clusters, equating with a cluster infestation rate of 50–60% (IOC, 2007). Every year, when the olive flower buds have opened, olive growers apply broad-spectrum insecticides to combat olive moth *Prays oleae* (Lepidoptera: Yponomeutidae) and olive psyllid *E. olivina* at the same time. Twenty-eight insecticides have been approved to fight olive psyllid. The active ingredients are basically organophosphate and pyrethroid (Ezzahiri *et al*., 2013). These insecticides impact on non-target organisms (Kovanci *et al*., 2005) and consumer health by causing poisoning (Meehan *et al*., 2011); they are also the cause of the resurgence of secondary pests and resistant strains. The disadvantages of pesticides have driven researchers to explore other environmentally friendly means of control, such as botanical pesticides (Dibo *et al.* 2010; Meftah *et al*., 2011) and host plant resistance. The development of resistant varieties is an effective complementary approach in integrated control and is believed to help reduce the extent of insect pest losses (Jallow *et al.,* 2004).

The relations between entomological species and host plants are governed by the morphological, physical, physiological and chemical traits of the plants (size, shape, presence of epicuticular waxes and trichomes, phenological stage, plant colour, secondary metabolites) (Harborne, 1993; Berenbaum, 1995; Geiger and Gutierrez, 2000; Smith, 2005). These characteristics can disrupt insect behaviour (antixenosis), in particular mating, oviposition and feeding (Pilson, 2000; Painter, 1951 in Srinivasan and Uthamasamy, 2005; Smith and Clément, 2012). Cates (1980) reported that secondary metabolite synthesis occurs above all in young plant organs where the nutrients sought by the pests are concentrated (Karley *et al*., 2002). Herbivorous insects possess specific receptors of these secondary substances that enable them to reject the plant as a source of food (Schroeder and Hilker, 2008) while some insects are capable of using these substances or degradation products to locate their host plants. Hence, the quality of the plant is determined, inter alia, by its chemical composition, particularly the concentrations of secondary metabolites (Cai *et al*., 2004) and primary compounds, including nitrogen (Awmack and Leather, 2002). Generally, secondary plant molecules are released when the plant suffers damage such as attacks from phytophagous pests (Berenbaum, 1995). Thus, they are a means of defence against attack from bio-aggressors (Feeny, 1976; Harborne 1993). According to a study conducted by Zouiten *et al.* (2000) on olive–psyllid interaction, phenolic compounds are potentially involved in post-attack plant reaction. These authors showed that the phenol content of young shoots of varieties that come under less attack from *E. olivina* was two times higher than that of more sensitive varieties. Consequently, host plant variety significantly affects phytophagous growth and development via the nutritional quality and/or effect of the plant defence compounds (Awmack and Leather, 2002). Michalek *et al.* (1996) demonstrated that phenolic compounds may be involved in plant defence mechanisms against pest infections by inhibiting fungal development. Inoculation of olive shoots with a conidial suspension of *Verticillium dahliae* resulted in modifications of the phenolic metabolism (flavone and insoluble phenol contents) and wilting towards the 20th day after inoculation. As a result, there was a post-infection increase in the phenol content of the cell wall, which was 1.6 times higher than in the controls. The esterified phenols in the wall basically comprise ferulic and p-coumaric acid (Elboustani *et al.*, 1998). In addition, the secondary substances provoke a reduction in insect attacks as a result of a decrease in the nutritional value or palatability of the plant tissues and the presence of toxins or repellents (Gershenzon and Croteau 1991; Harborne 1993; Simmonds, 2001), in this specific case, tannins, methylisoborneol and myristicin (Metraux and Raskin, 1993). This may affect insect development and reproduction (antibiosis) (Awmack and Leather, 2002; Stamp, 2003; Smith, 2005), or may have an indirect effect by increasing insect exposure to natural enemies owing to a long developmental period (Sarfraz *et al.*, 2006). Insect–host plant interaction is also influenced by microclimatic conditions (Zalucki *et al.*, 2002; Villalpando *et al.*, 2009). However, some insects develop biochemical adaptation mechanisms to the secondary molecules emitted by their host plants (Lamb, 1989). These molecules may be precursors of pheromones or of defence substances such as alcaloids, isoflavonoids or saponins produced by certain plants and may be used by phytophagous pests to protect themselves from their natural predators (Harborne, 1993). Other secondary molecules of the plant such as tangeretin are trophic source indicators for phytophagous insects on which they may exert an attractant influence (Harborne, 1990; Metraux and Raskin, 1993; Smith, 2005). As regards the importance of nitrogen in protein synthesis, the content of this element is decisive to the nutritional quality of the plant for a wide range of phytophagous insects (Wilkinson and Douglas 2003). According to Catling (1972), the large quantities of nitrogen in the leaves of citrus fruits stimulate oviposition by *Trioza erytreae*. The high nitrogen content of the host plants increases the rate of development and survival of phytophagous insects (Jonas and Joern, 2008).

Studies conducted on the biology of *E. olivina* in the region of Haouz (Morocco) (Ouguas and Hilal, 1995; Hilal *et al.*, 1997; Tajnari, 2001) and in the central region of Morocco (Meftah *et al.*, 2014), where the insect has a bivoltine cycle, have given a better insight into its population dynamics in the field. Conversely, the results of research evaluating olive varietal sensitivity to *E. olivina* in the region of Marrakech (Ouguas and Hilal, 1995; Zouiten *et al.*, 2000; Zouiten and El Hadrami, 2001; Zouiten, 2002) cannot be adapted as the basis for an integrated control strategy to combat this bio-aggressor in central Morocco (Meknès region). As has been noted in the case of other homopterans (Morgan *et al.*, 2001), varietal selection programmes have to take into account the impact of geographical location on the insect. No data are currently available on the demographic parameters of *E. olivina,* which are one of the chief determinants of varietal resistance/sensitivity to this pest.

This study reports the biological and demographic performance of *E. olivina* reared on young plants of four varieties of olive cultivated in enclosed conditions in the central region of Morocco, with the aim of facilitating the design of integrated management of *E. olivina* on different varieties of olive.

Materials and methods

Varieties of olive

The plants used in the study were one year old and were obtained from an accredited nursery in the Meknès region that produces certified olive plants. The varieties tested were 'Picholine marocaine' (polyclonal variety) and 'Haouzia' (a clone of the 'Picholine marocaine') (Boulouha *et al.*, 1992), both dual-purpose varieties used for oil or table olive production depending on the period of ripening, 'Arbequina', an oil variety characterised by its small fruit and high oil yields, and 'Manzanilla', a variety with large fruit basically intended for table olive production (IOC, *2000*).

Psyllid strains

Adult olive psyllids that developed from L_5 nymphs of the second spring generation were collected from 'Picholine marocaine' olive trees planted in an experimental plot of the *Institut des Techniciens Spécialisés en Horticulture de Meknès* (I.T.S.H.M.) (latitude: 33.524° N, longitude: 5.326° W and altitude: 544 m). They were then harvested using the beating tray technique (Reboulet, 1999), separated by sex under a stereo microscope, placed in Petri dishes and used to infest shoots of the varieties tested.

Testing

The varietal non-choice trial was conducted in a chamber at the I.T.S.H.M. at a temperature and relative humidity varying respectively from 11.9 °C to 33.5 °C and from 37.5% to 90.3% (Figure 1) and in daylight during the period from February to July 2012.

The olive plants were cultivated in black polyethylene bags, 1.5 L volume, and placed on metal shelving raised 1 m above the ground. Each young olive plant was infested with two pairs of *E. olivina* with the aid of a fine paintbrush. The plant was then covered with a piece of muslin mounted on a galvanised iron frame (Ø = 3.2 mm) measuring 20 x 20 x 100 cm (length x width x depth) to stop the adults from escaping. Five replicates were performed for each variety.

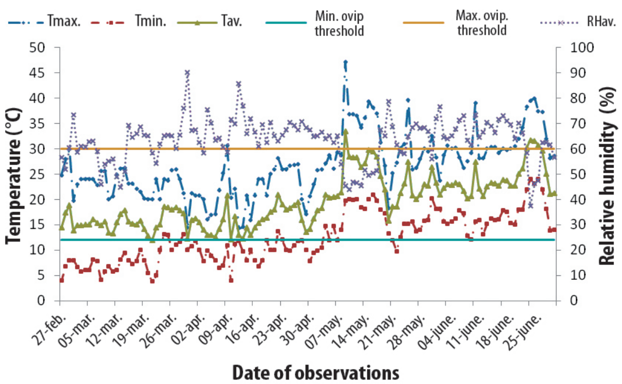

Figure 1: Temperature and relative humidity conditions in enclosed conditions during the study of olive psyllid development on four varieties of olive

Observations were taken every four days from the time the olive varieties were first infested with the pairs of psyllids until the emergence of the new adults. For each observation, the different stages of psyllid (eggs, nymphs and adults) were counted under stereo microscope and insect status was determined (alive or dead). The biological parameters measured for each variety were adult life span, fecundity (= number of eggs laid during female lifetime), duration of oviposition, fertility of eggs laid on each plant (= number of eggs hatched/ number of eggs laid x 100), embryo mortality rate (number of eggs laid - number of eggs hatched/ number of eggs laid x 100), nymph mortality rate (number of eggs hatched - number of adults emerged)/number of eggs hatched x 100), number of adults emerged by sex, success rate (number of adult offspring/number of eggs laid x 100), survival rate (*lx*) and age-specific fecundity (*mx*) (Southwood and Henderson, 2000).

At the end of the trial, the demographic parameters of *E. olivina* reared on four varieties of olive were calculated according to Carey (1993; 2001). These comprised the net reproduction rate (R_0), sex ratio (= number of males/number of females) (*S*), intrinsic rate of increase (*rm*), finite rate of increase (λ), average generation length (*T*) and population doubling time (*Dt*).

Data analysis

Student's *t*-test (5%) was used to detect potential differences between the biological parameters (lifespan, fecundity, fertility, length of oviposition, offspring, length of embryo development, generation length and mortality). To ascertain the effect of variety on the demographic parameters (R_0, r_m, λ, *T*, *Dt* and *S*) of *E. olivina* reared on the four varieties of olive, one-way analysis of variance was performed followed by Scheffe's test at a threshold of 5%. The statistical analyses were performed on raw data in the case of the quantitative variables or on data transformed into Arcsin√ (percentage) in the case of ratios. The survival curves were constructed according to Kaplan-Meier (1958). The mean lifespan of both sexes of psyllid on the four varieties of olive tested was determined according to the logrank test. Cluster analysis was performed according to the method of Ward using Statistica version 7 software to classify the varieties by their response to psyllid attack. The analysis was conducted on all the mean standardised values of the biological and demographic parameters measured.

Results and discussion

Effect of variety on biological parameters

Lifespan

When released on the olive plants, adult psyllid lifespan varied according to variety, ranging between 24 and 44 days for the males and between 26 and 50 days for the females (Figures 2 and 3), with pronounced individual variability. The coefficients of variation oscillated between 8.25 and 21.21%. Within the same variety, females lived longer than males and remained longer on the plants (Table 1). In this trial, 'Haouzia' was more favourable to adult survival, followed by 'Arbequina', 'Picholine marocaine' and 'Manzanilla' (Figures 2 and 3). In another species of psyllid, *Cacopylla pyri* (L.), Kapatos and Stratopoulou (1996) reported variations in adult lifespan from 22 to 28 days under natural conditions according to season (spring and autumn).

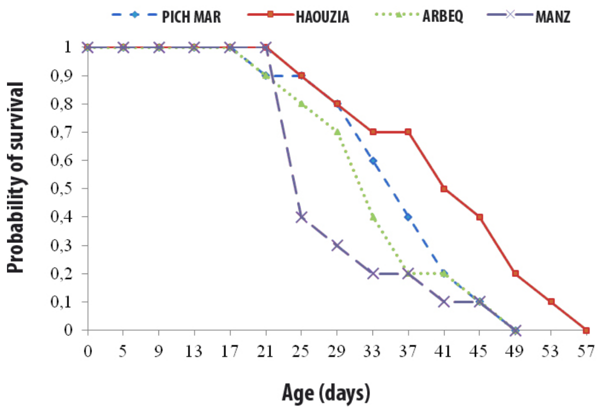

Figure 2: Female psyllid lifespan on the varieties of olive tested (N=10/variety) (the logrank test did not reveal any significant difference between the survival curves for the varieties tested)

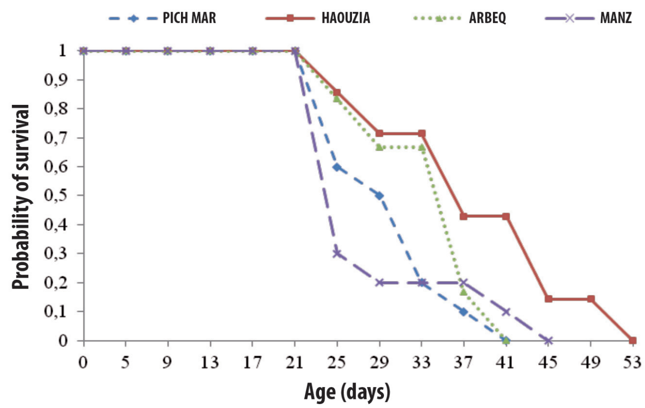

Figure 3: Male psyllid lifespan on the varieties of olive tested (N=10/variety) (the logrank test did not reveal any significant difference between the survival curves for the varieties tested)

Table 1: Biological parameters (mean ± standard deviation) of olive psyllid reared on olive varieties

Parameters	Variety			
	Picholine marocaine	Haouzia	Arbequina	Manzanilla
M. Ad. lifespan (d)	31.6±2.61	33.2±4.38	34.0±7.21	29.6±4.10
F. Ad. lifespan (d)	37.6±6.54	39.2±7.01	34.4±4.77	31.2±4.82
Fecundity (Eggs/2 females)	654.60±194.11a	877.00±265.63b	634.40±256.81a	526.60±279.01c
Average oviposition length (d)	33.8±5,93a	44.2±4.38b	37.0±7a	31.4±10.81a
Fertility (%)	39.81±7.83a	38.78±11.67a	63.90±13.20b	44.14±7.52a
Length of embryo development (d)	14.48±21.00a	16.95±22.01b	7.89±9.58c	10.08±12.61c
Length of nymph development (d)	43.24±29.79a	49.08±33.48b	61.87±24.48b	55.82±22.11c
Female offspring (N)	123a	240b	131c	137c
Male offspring (N)	105a	193b	107a	108a
Success rate (%)	31.6±2.61	33.2±4.38	34.0±7.21	29.6±4.10
Embryo mortality (%)	60.19±7,83a	61.22±11.67a	36.10±13.2b	55.86±7.52c
Nymph mortality (%)	81.92±2.14a	72.65±5.41b	87.50±2.85a	78.82±5.23b

M. Ad.: Male adults F. Ad.: Female adults
Values followed by the same letter on the same line do not differ statistically (one-way analysis of variance followed by Student's t test at a level of 5%).

Fecundity

When released on the varieties tested, *E. olivina* started to lay eggs as of the 6th day of the starting date of the test in the case of 'Haouzia' and as of the 10th day for the other varieties (Figure 4). Psyllid oviposition lasted from 44 to 52 days depending on the variety concerned. Optimal oviposition was recorded in the second week on 'Picholine marocaine', in the third week on 'Arbequina' and 'Haouzia' and in the fourth week on 'Manzanilla' (Figure 4).

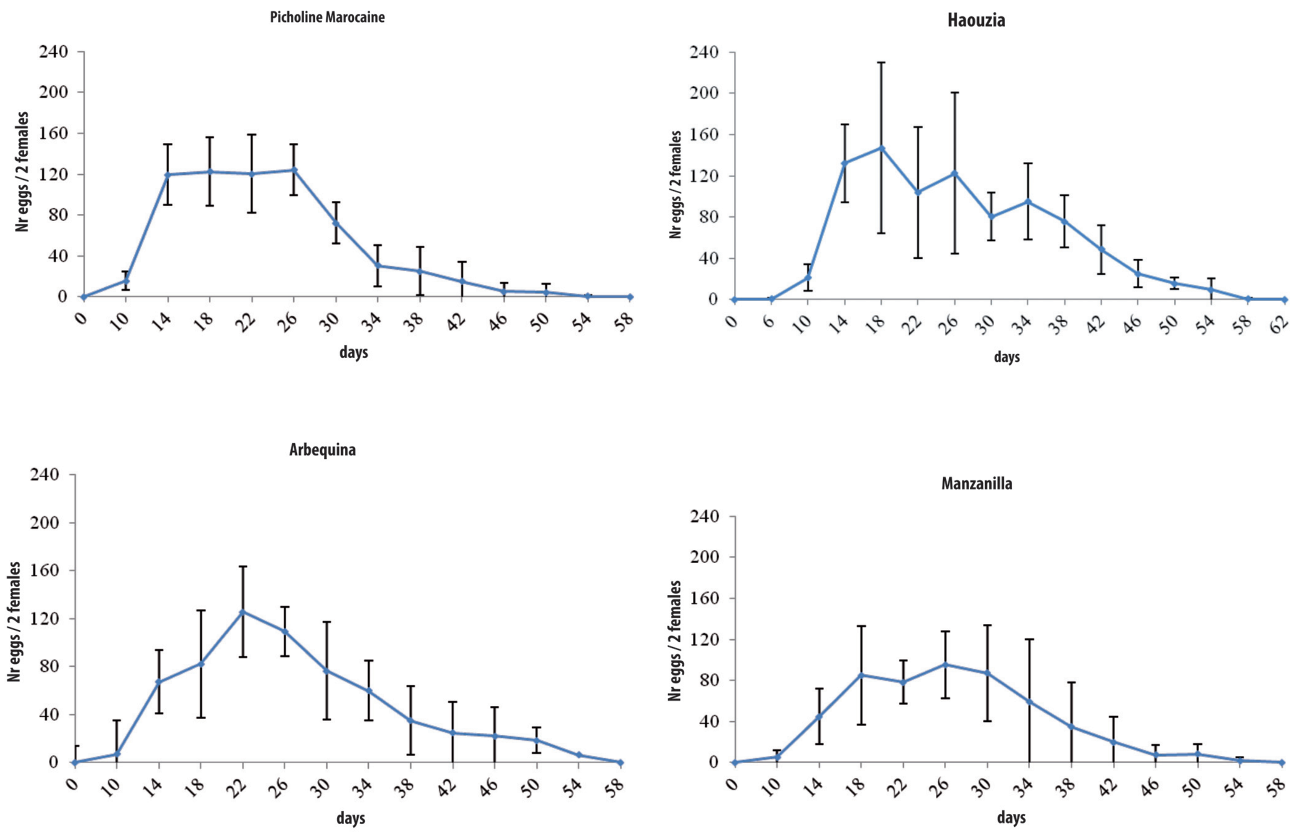

Figure 4: Fecundity time line of olive psyllid reared on four varieties of olive in enclosed conditions

The longest oviposition period was recorded for 'Haouzia' (Table 1). During the oviposition period, the fecundity extremes ranged from 191 to 1 242 eggs/2 females according to variety and displayed pronounced individual variability (coefficients of variation = 29.65–52.98%). Although significant differences did not exist between the varieties tested, the highest fecundity was observed on 'Haouzia' and the lowest on 'Manzanilla' (Table 1). Hence, 'Haouzia' was more conducive as an oviposition site for *E. olivina* while the other varieties were relatively less so (Table 1). In this trial, psyllid fecundity was largely dependent on female lifespan (R^2 = 0.79). Asadi *et al.* (2011) reported that the fecundity of *E. pakistanica* reared in the laboratory at 20±1 °C, 60±5% relative humidity and a photoperiod of 16:08 hours (L:D) was influenced by the varieties of olive tested ('Fishomi', 'Shenge', 'Oil', 'Yellow'). The maximum was recorded on 'Yellow' (398±18 eggs/female) and the minimum on 'Oil' (151±7.0 eggs/female) while the fecundity recorded on 'Fishomi' was 189±14 eggs/female. According to the same authors, in-orchard fecundity on 'Fishomi' was only 103.26±10.39 eggs/female. Other research on the effect of olive variety on *E. olivina* fecundity conducted by Zouiten *et al.* (1998; 2000) and Zouiten and El Hadrami (2001) has shown that among the varieties tested ('Santa Catarina', 'Gordale', 'Lucques', 'Frantoio' and 'Arbequina'), 'Santa Catarina' and 'Gordale' were more conducive to oviposition than the other varieties studied and that the differences in fecundity were believed to be due to the effect on the insect of constituent phenolic compounds in the olive tissue (oleuropein,3,4-dihydroxyphenylethanol and caffeic acid). In addition, observations of Zouiten *et al.* (2000; 2004) revealed that 3,4-dihydroxyphenylethanol is a potential phenolic involved in olive–psyllid interaction. This compound may act directly by acting as a strong proteinase or amylase inhibitor in the insect or indirectly by activating the proteinase genes in the host plant to cause a loss of psyllid appetite, thus affecting psyllid oviposition and leading to a higher mortality rate.

According to Simmonds (2001) quercetin, which is a constituent fraction of phenolic compounds, may block oviposition in certain insects. Oviposition lasts between 21 and 49 days according to the variety tested; the shortest length was recorded on 'Manzanilla' (31.4±10.81 days) and the longest on 'Haouzia' (44.2±4.38 days) (Table 1). Oviposition duration did not differ significantly. Ksantini *et al.* (2002) recorded an oviposition length of 37 days in *E. olivina* reared in the laboratory at a constant temperature of 25 °C, a relative humidity of 70±5% and a photoperiod of short days (10:14) on 'Chemlali' olive shoots soaked in Knop's nutrient solution. In laboratory-reared *E. pakistanica* oviposition lasts around 34 days (Asadi *et al.*, 2011).

Fertility

In this study, fertility ranged between 26.24% and 78.31% of the eggs hatched on each of the varieties and displayed great variability ranging between 17.03 and 30.08%. The percentage egg hatching rate differed statistically between varieties ($F_{cal} = 6.38 > F_{(0.05;\ 3-19)} = 3.24$). The highest fertility rate was recorded on 'Arbequina' (63.90±13.20%) and the lowest on 'Haouzia' (38.78±11.67%) while the rates recorded on 'Manzanilla' and 'Picholine marocaine' were 44.14±7.52 and 39.81±7.83% respectively of the eggs laid (Table 1). Egg embryo development was relatively long on 'Haouzia' (16.95±22.01) and shortest on "Arbequina' with 7.89±9.58 (Table 1). These results are comparable to those obtained by Ksantini (1986), who recorded an olive psyllid embryo development period of 7–14 days as the temperature went from 30 °C to 20 °C.

Nymphal growth

There are five nymphal growth stages in *E. olivina*. The maximum duration was recorded on 'Arbequina' (61.87±24.48) and the minimum on 'Picholine marocaine' (43.24±29.79) (Table 1), which suggests that this last variety is less favourable to olive psyllid nymph development. The total mortality rate of the nymphal instars of *E. olivina* reared on the four varieties of olive tested is given in Table 1. Comparison of the mortality rates using Student's *t*-test revealed significant between-variety differences: the maximum was recorded on 'Arbequina' (87.50±2.85%) and the minimum on 'Haouzia' (72.65±5.41%) (Table 1); the respective coefficients of variation were 3.25 and 7.45%. This last variety is more conducive to the development of the immature instars, as has been observed by Ouguas (1994) and Zouiten *et al.* (1998). The differences in the mortality rates of the psyllid nymphal instars recorded for the varieties tested could be linked to the nature and abundance of certain phenolic fractions that are present separately in each variety. These compounds may affect the digestive capacity of the insect and their assimilation (Liu *et al.*, 2004) and may therefore lead to its death. Using HPLC chemical testing, Zouiten (2002) demonstrated that the constituent fractions of phenols vary in quantity in the varieties of olive cultivated in the Haouz region (Morocco), more particularly oleuropein, rutin and other derivatives of quercetin, luteolin-7-glucoside, verbascoside and 3,4-dihydroxyphenylethanol and exert a strong effect on olive psyllid reproductive parameters. This has also been confirmed by Ouguas *et al.* (2006) on treating psyllids reared on the 'Ménara' and 'Arbequina' varieties with phenolic compounds extracted from young shoots of the 'Santa Catarina' variety. Asadi *et al.* (2011) documented the effect of different olive varieties on the biological parameters of *E. pakistanica*. In this study, the high mortality rate of the different nymphal instars of the olive psyllid is also believed to be due to the high temperatures recorded during the period of the study. In point of fact, temperatures reached 30 °C or more, which is lethal for the olive psyllid, for 15 days in May and 17 days in June 2012 (Figure 1). The lethal effect of high temperatures on *E. olivina* has already been reported by Chermiti (1989), Tajnari (2001), Ksantini *et al.* (2002) and Ksantini (2003). According to the last authors, the mean lifespan of *E. olivina* decreases as the temperature exceeds or approaches 30 °C. Amin *et al.* (2013) drew the same conclusion for *E. straminea* reared in the laboratory at three constant temperatures (20, 25 and 30 °C).

Success rate

Female emergence started on day 37 after oviposition, well ahead of male emergence on 'Picholine marocaine' and 'Haouzia' whereas females and males did not emerge on 'Manzanilla' until day 45 after oviposition. Conversely, male emergence occurred before female emergence on 'Arbequina', occurring on days 37 and 45 after oviposition respectively (Figures 5 and 6). The emergence rates on 'Manzanilla', 'Arbequina' and 'Picholine marocaine' were respectively 9.30, 7.50 and 6.97% while they reached 9.87% of the eggs hatched on 'Haouzia'. This last variety proved to be more conducive to the insect reaching the imaginal stage of *E. olivina* (Table 1). The number of adult male and female offspring obtained from 10 pairs per olive variety varied greatly. The maximum total number of adults was recorded for 'Haouzia' (433); 240 were adult females, 50% of which emerged 63.21 days after oviposition and 193 were adult males, 50% of which were recorded 62.83 days after oviposition. In the case of the 'Manzanilla' variety, 245 adults were recorded (137 females and 108 males), 50% of which emerged 65.69 and 62.77 days after oviposition whereas the total number recorded on 'Arbequina' was 238 adults, of which 131 were female and 107 male, 50% of which emerged respectively 69.57 and 67.19 days after oviposition. Lastly, the lowest emergence rate was observed for 'Picholine marocaine': 228 adults, of which 123 female and 105 male, 50% of which were recorded respectively 55.71 and 55.52 days after egg deposition. In this trial, 'Haouzia' proved to be the most favourable to the development of *E. olivina*, followed by 'Manzanilla', 'Arbequina' and 'Picholine marocaine' (Table 1). 'Picholine marocaine' is the most tolerant of psyllid attack and produces a larger volume of biomass than the other varieties examined (Smith, 2005). These results are comparable to those obtained by Asadi *et al*. (2011) in controlled laboratory conditions in Shiraz (Iran) for *E. pakistanica* reared on four varieties of olive ('Fishomi', 'Yellow', 'Oil' and 'Shenge').

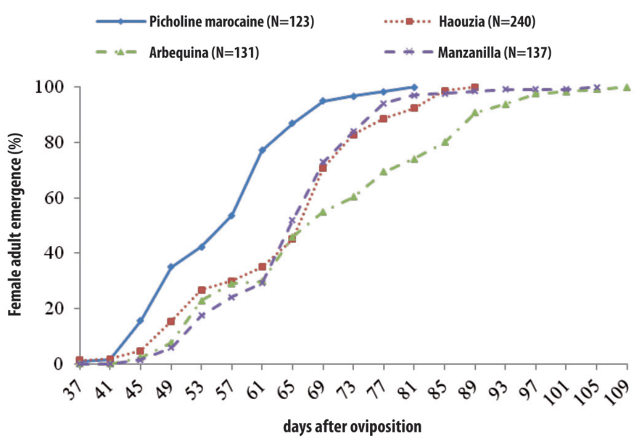

Figure 5: Time line of adult female olive psyllid emergence on four varieties of olive

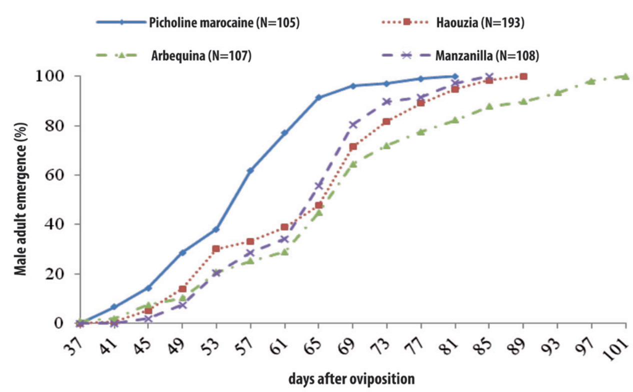

Figure 6: Time line of adult male olive psyllid emergence on four varieties of olive

Effect of variety on demographic parameters

The age-specific survival rates (l_x) of *E. olivina* on the four varieties tested are plotted in Figure 7. As can be seen, 'Haouzia' stands out from the other varieties, which share the same survival profile. The highest and lowest mortality rates of the nymphal instars were recorded respectively on 'Arbequina' (87.50±2.85%) and 'Haouzia' (72.65±5.41%) (Table 1). This suggests that this last variety is better suited to the development of immature instars of *E. olivina*. The highest mortality rate was observed for the L_5 nymphal instars, with a maximum of 27.36% on 'Picholine marocaine' and a minimum of 14.02% on 'Haouzia'. The survival curves for *E. olivina* on the four varieties are conventional type 1. The species is affected by heavy mortality in the young stages (eggs and nymphs) (Figure 7). These results are comparable to those obtained by Asadi *et al*. (2011) for *E. pakistanica* reared on four varieties of olive ('Fishomi', 'Yellow', 'Oil' and 'Shenge') in that they reported that the L_5 instars are the most vulnerable and have the highest mortality rate of the nymphal instars.

Specific fecundity (m_x) varied from 1 to 29 females/day on 'Picholine marocaine', from 1 to 62 on 'Haouzia', from 1 to 21 on 'Arbequina' and from 1 to 31 on 'Manzanilla' (Figure 7). Maximum fecundity was observed 74, 78, 70 and 70 days after plant infestation respectively on 'Picholine marocaine' (29 females/day), 'Haouzia' (62 females/day), 'Arbequina' (21 females/day) and 'Manzanilla' (31 females/day). In this instance too, 'Haouzia' is the most conducive to the psyllid.

Olive psyllid life expectancy (*ex*) varied according to

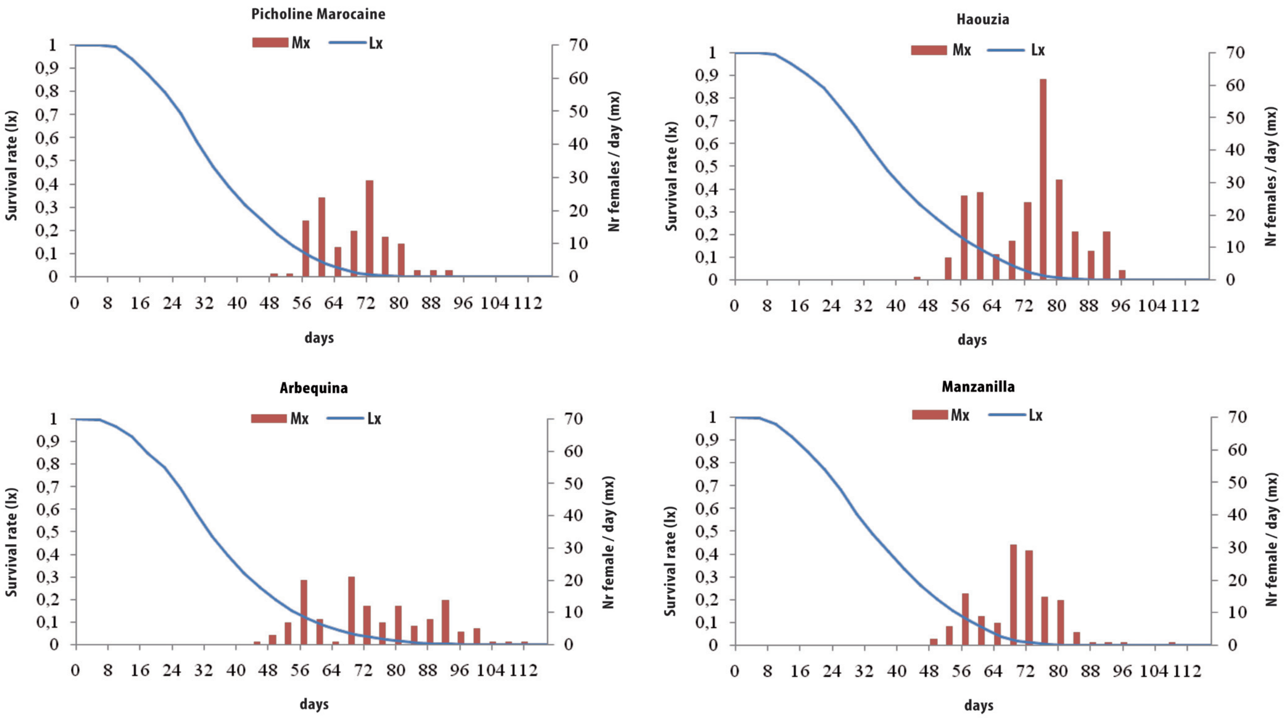

Figure 7: Survival trend *(lx)*of sexually mature olive psyllid females *(mx)* on four varieties of olive

variety and within the same variety depending on the stage concerned. For eggs, it ranged from 1.91 days on 'Haouzia' to 2.80 days on 'Arbequina' whereas for the other stages life expectancy varied from 9.45 days on 'Arbequina' to 10.18 days on 'Haouzia'. L_1 had the longest life expectancy: from 3.18 days on 'Manzanilla' to 3.41 days on 'Haouzia' (Figure 8).

Table 2 reports the demographic parameters of the

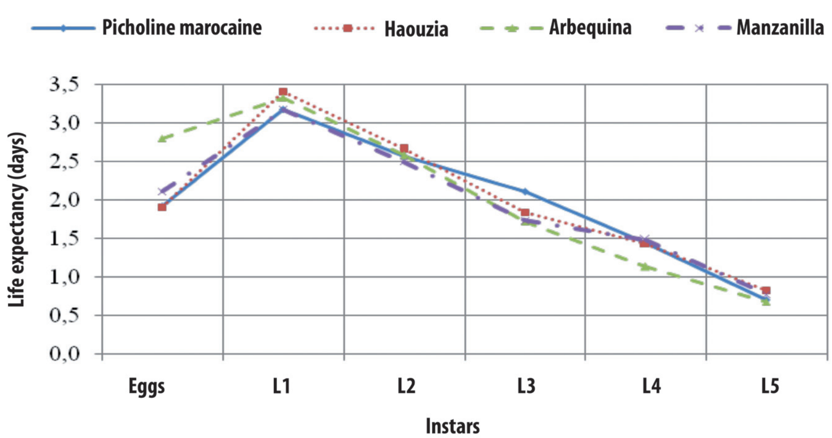

Figure 8: Life expectancy *(ex)* by stage of olive psyllid reared on four varieties of olive

olive psyllid populations (R_0, r_m, λ, *T*, *Dt* and *S*) on the four varieties. The net reproductive rate (R_0) varied significantly by variety ($F_{calculated} = 3.83 > F_{(0.05; 3 - 19)} = 3.24$). The highest rate was recorded for 'Haouzia' (24.00±6.35) and the lowest for 'Picholine marocaine' (12.30±3.77). The intrinsic rate of increase (r_m), which is considered an important indicator of the potential performance of the *E. olivina* population, was significantly affected by the varieties ($F_{calculated} = 3.67 > F_{(0.05; 3 - 19)} = 3.24$) and varied from 0.04±0.00 individuals/day on 'Picholine marocaine' to 0.05±0.00 individuals/day on 'Haouzia'. The psyllid population developed rapidly on this last variety. Asadi *et al*. (2011) recorded higher r_m values for *E. pakistanica* on 'Fishomi', 'Yellow', 'Oil' and 'Shenge', ranging from 0.14 to 0.17 individuals/day while Amin *et al*. (2013) observed an r_m value of 0.03 individuals/day in *E. straminea* bred at a constant temperature of 25 °C. The finite rate of increase (λ) in *E. olivina* also showed significant differences between the four varieties ($F_{calculated} = 3.68 > F_{(0.05; 3 - 19)} = 3.24$). The values were 1.04±0.01 females/day on 'Arbequina' and 'Manzanilla', 1.05±0.00 females/day on 'Picholine marocaine' and 1.05±0.1 females/day on 'Haouzia'. These results are comparable to those obtained by Asadi *et al.* (2011) who recorded λ values varying from 1.15 to 1.18 females/day in *E. pakistanica* reared on four varieties of olive. For their part, Asadi *et al*. (2013) reported a value of 1.03 females/day in *E. straminea* reared at a constant temperature of 25 °C. Average generation length (*T*) was 57.73±8.79 days for 'Picholine marocaine' and 69.76±14.90 days for 'Arbequina'. Conversely, the *T* value for the other two varieties did not differ significantly. Amin *et al*. (2013) documented an average duration of 53.50 days for generations of *E. straminea* reared at a constant temperature of 25 °C. The time it took the population to double (*Dt*) was statistically longer for 'Arbequina' (18.82 days) and shorter for 'Haouzia' (14.19 days), thus suggesting that this variety is more conducive to insect population doubling. The maximum sex ratio (0.85) was recorded on 'Picholine marocaine' and the minimum (0.79) on 'Manzanilla'. Amin *et al*. (2013) recorded a sex ratio of approximately 0.93 for *E. straminea* reared at a constant temperature of 25 °C. However, sex ratios under controlled conditions may differ from those observed in field conditions. In the orchard, besides being controlled by abiotic factors olive psyllid populations are also controlled by numerous predators (insects, spiders and acarids). The sex ratio within the psyllid population may also decrease owing to the fact that the females have a longer lifespan than the males.

Table 2: Demographic parameters of olive psyllid reared on four varieties of olive

Parameters	Variety			
	'Picholine marocaine'	'Haouzia'	'Arbequina'	'Manzanilla'
Net reproduction rate (R_0) (♀/generation)	12.30±3.77a	24.0±6.35b	13.10±6.94a	13.70±7.49a
Intrinsic rate of increase (r_m: ♀/♀/*d*)	0.04±0.00a	0.05±0.00b	0.04±0.01a	0.04±0.01a
Finite rate of increase (λ: ♀/♀/*d*)	1.04±0.00a	1.05±0.00b	1.04±0.01a	1.04±0.01a
Average generation length (*T*: *d*)	57.73±8.79a	66.03±11.47b	69.76±14.90c	65.91±9.50b
Population doubling time (*Dt*: *d*)	15.99±1.50a	14.44±1.41a	20.52±4.61b	19.39±5.30b
Sex ratio (*S*)	0.85a	0.80b	0.82a	0.79b

Values followed by the same letter on the same line do not differ statistically (one-way analysis of variance followed by Student's *t*-test at a level of 5%).

The variability in these growth parameters of the olive psyllid population may be linked to intrinsic and extrinsic factors, specifically the temperature conditions recorded during the trial and the morphological (shoot density, leaf shape and colour, cuticle thickness,…) and/or chemical differences (presence of allelochemical molecules) between the varieties tested (Syed and Abro, 2003). This may play an important role in the variability in their resistance to psyllid, as documented in several varieties of olive by Zouiten *et al.* in 2001.

Lastly, the four varieties can be classified according to their sensitivity to olive psyllid (Figure 9) by taking into account all the biological and demographic parameters of *E. olivina* that were measured. It emerges that 'Haouzia' is the most conducive to the development of the insect, followed by 'Manzanilla', 'Arbequina' and 'Picholine marocaine', thus implying differing sensitivity to the psyllid.

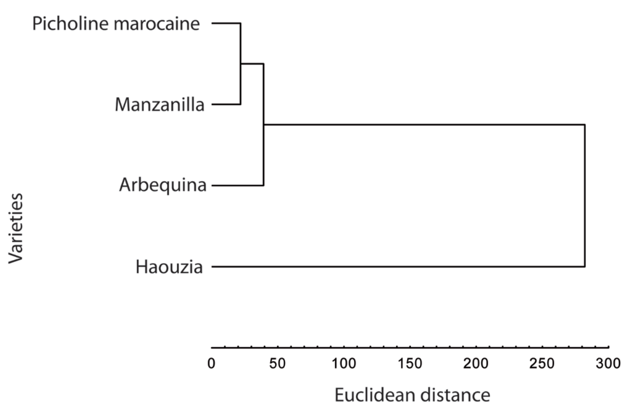

Figure 9: Dendrogram of the four host varieties of olive psyllid according to the biological and demographic parameters measured (Ward method)

Conclusions

Varietal resistance is a pest control method that is compatible with chemical and biological control; moreover, it does not affect the environment or consumers in a context of sustainable development (Wilson and Huffaker, 1976; Razmjou *et al*., 2006). In point of fact, while remaining compatible with chemical control, varietal resistance influences the population dynamics of the pests by affecting their intrinsic rates of increase and improving the effectiveness of their natural enemies (Greenberg *et al*., 2001; Smith, 2005; Razmjou *et al*., 2006; 2013). This research has shown that the growth parameters of the *E. olivina* populations were affected by the varieties tested among which 'Haouzia' is the most conducive to the development of the psyllid population. The psyllid has a longer lifespan and lays more eggs on this variety. Its net reproduction rate and intrinsic rate of increase are also higher. In addition, this last parameter (r_m) is widely used to assess the level of plant resistance to insects (Van Lenteren and Noldus, 1990; Razmjou *et al*. 2006). The sensitivity of 'Haouzia' may be due to the fact that certain nutrients are more abundant in this variety or to the high content of allelochemical substances in the other varieties tested compared with it. 'Arbequina', 'Manzanilla' and 'Picholine marocaine' proved to be less favourable to infestation by *E. olivina*. The values recorded for the research parameters were relatively low, particularly for 'Picholine marocaine'; this suggests the probable presence of allelochemical substances which act as antixenotic agents and/or antibiotics in this variety, grown on more than 86% of olive orchard area. It should be given a central part in the establishment of new orchards. However, the effect of the psyllid on olive production in crop bearing orchards has yet to be determined as well as the allelochemical substances involved in varietal resistance.

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Genetic diversity of Arab varieties of olive held in the Boughrara National Olive Germplasm Bank (Sfax, Tunisia)

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Abstract

The Olive Germplasm Bank was established at Boughrara (Sfax, Tunisia) in 1992. The goal of this centre, considered to be one of the most important gene banks in the Mediterranean region, is to protect olive germplasm from extinction and to use it for varietal breeding. Since it first started to operate, the collection has expanded to include both autochthonous and non-autochthonous varieties. At present, it houses 201 genotypes and varieties, 147 of which are Tunisian in origin while the remaining 54 are foreign. Twenty-four have been obtained from grafts and 177 from rooted cuttings.

The Bank houses varieties from other Arab countries, specifically Algeria, Lebanon, Libya, Morocco and Syria, although on a very limited scale (no more than six varieties). Monitoring of olive crop production per tree during the period 2007–2013 has revealed the superiority of the Moroccan and Algerian varieties (average production: 4.3–12.84 kg) over the varieties from Lebanon, Libya and Syria. Hence, the Maghrebi varieties can be said to be better adapted to the Tunisian climate. Some of the Arab varieties in the Bank have been used in the programme for the genetic improvement of the 'Chemlali de Sfax' variety through controlled hybridisation with the 'Sigoise' and Lebanese 'Soury' varieties, which gave rise to 54 and 59 hybrids, respectively. All are currently crop-bearing and are undergoing evaluation to select those that give the oils with the best fatty acid composition.

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Introduction

Olive growing is one of the most important branches of agriculture in Tunisia where 70 million olive trees grow on 1.8 million hectares of land (International Olive Council, 2012). Between 2001 and 2010 Tunisia exported 118 000 t of olive oil on average, positioning it in second place in the world ranking after the European Union (International Olive Council, 2012). This tonnage represents 40% of Tunisia's total agricultural exports (International Olive Council, 2012).

Work has been underway for many years on surveying the genetic olive heritage of Tunisia although it intensified with the creation of the *Institut de l'Olivier* (Olive Tree Institute) in 1983. The first documented sources on the genetic resources of Tunisia were published by Mehri and Hellali (1995) who meticulously described 15 autochthonous varieties and three foreign varieties. In 2002, a second batch of varietal cataloguing was published by Trigui and Msallem (2002) who described 56 native varieties.

The phenotypical characterisation of the olive covered all the plant organs: leaf, fruit, inflorescence and stone. Characterisation of this type was first carried out at international level by the Food and Agricultural Organisation of the United Nations (FAO, 1981) and Rallo and Barranco (1984). Subsequently, characterisation moved further forward in studies conducted by the International Olive Council (1997), in which as many as 30 phenotypical traits were determined on the basis of the leaf (4), fruit (10), stone (10), inflorescence (2) and tree (4). This research served as the basis for the publication of a major catalogue reporting 134 olive varieties from 23 countries (International Olive Council, 2000).

After surveying and characterisation, the next task in Tunisia was to conserve the genetic olive heritage. To do so, the Olive Germplasm Bank was set up in Sfax to conserve specific varieties, propagated mainly by vegetative means. Two world olive collections were also created, one in Marrakech and the other in Cordoba (International Olive Council, 2014). These measures were taken under the umbrella of the *Project for the Conservation, Characterisation, Collection and Utilisation of Genetic Resources in Olive* financed by the Common Fund for Commodities (2014) and supervised by the International Olive Council in five participant countries: Algeria, Egypt, Morocco, Syria and Tunisia.

The varieties held in these centres were used as the basis for hybridisation aimed at improving specific genetic traits. The Common Fund for Commodities (2014) financed the *Genetic Olive Improvement Project* for this purpose in four Arab countries: Algeria, Egypt, Morocco and Tunisia. In Tunisia, genetic improvement focused on the 'Chemlali de Sfax', 'Meski' and 'Chétoui' varieties, which were handicapped by some of their characteristics (Trigui, 1996), for instance the first variety has an unbalanced fatty acid composition which affects its marketing and packing (Grati-Kamoun and Khlif, 2001). In all, 1 200 hybrids were obtained under this project. Since 1997, they have been planted in Sfax where they are currently under assessment (*Institut de l'Olivier*, 2005).

This article is intended to give an overview of the Boughrara Olive Germplasm Bank (Sfax, Tunisia), with the focus on the varieties held, particularly Arab varieties, and their crop production.

Materials and methods

The Olive Germplasm Bank was set up in 1992 at the *Centre Sectoriel de Formation Professionnelle Agricole de l'Arboriculture* in Boughrara (Sfax, Tunisia). It is established on an 8 m x 12 m layout in rainfed conditions and receives the following cultural care:

- Shallow tillage 3–4 times a year;
- Organic fertilisation in winter;
- Post-harvest pruning, the frequency of which varies according to crop volume.

The number of genotypes constantly grows through the inclusion of new varieties identified during surveying. These undergo vegetative propagation at the Institute olive nursery or, if this fails, they are grafted.

Foreign genotypes have been obtained through bilateral cooperation programmes and under the IOC-funded genetic resources project. The Boughrara Bank also cooperates closely with the Cordoba and Marrakech world collections with which it exchanges germplasm.

The activities of the Germplasm Bank encompass the following every year:

- Planting of any new varieties;
- Verification of genotype identity, particularly in the case of new accessions
- Monitoring of crop production/tree.

Results and discussion

As can be seen from Figure 1, the Boughrara Bank has 201 varieties, 147 of which are autochthonous (73.13%). The remaining 54 varieties are foreign, of which only 15 are Arab. Hence, Arab varieties account for 7.46% of the total and 27.77% of the non-Tunisian varieties. The Arab varieties are from five countries: Algeria, Lebanon, Libya, Morocco and Syria (Table 1). Morocco and Syria are the countries that are most heavily represented, with five and six varieties respectively, while the other three countries are represented by only one variety each.

Comparison of these numbers of varieties with the varieties listed in the World Catalogue of Olive Varieties (International Olive Council, 2000) elicits numerous comments:

- The Boughrara Bank does not have varieties from Arab countries like Egypt and Jordan, even although they are Members of the IOC, or Palestine;
- It has only one variety from Algeria whereas five are cited in the World Catalogue;
- The Bank has only one variety from Libya, another IOC Member;
- It houses some varieties from Arab countries like Syria and Morocco which are not mentioned in the IOC World Catalogue, for instance 'Msabii', 'Dan' and 'Jlot' from Syria and 'Bouchouika', 'Meslala', 'Dahbia' and 'Noukal' from Morocco;
- Although it is recognised worldwide to be the cradle of olive growing (Damania, 1995), Palestine is not represented in the Boughrara Bank.

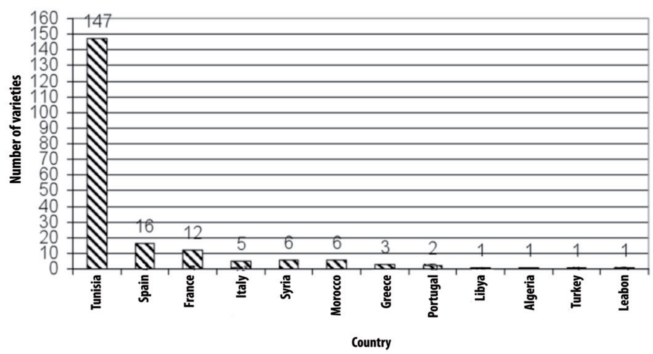

Figure 1: Breakdown, by country, of the varieties held in the Boughrara Bank

Table 1. Arab varieties held at the Boughrara Bank

Country	Varieties
Syria	Jlot, Msabii, Dan, Sorani, Abu satl muhazam, Kaissi
Morocco	Picholine marocaine, Haouzia, Bouchouika, Meslala, Dahbia, Noukal
Algeria	Sigoise
Lebanon	Soury (Lebanese)
Libya	Aswad kafra

The majority of the varieties planted at Boughrara (88.1% = 177 varieties) has been propagated by vegetative means (Table 2); the remaining 24 or 11.9% has been grafted.

Table 2. Method of propagation

Method of propagation	Cuttings	Graffing
Number	177	24
Percentage (%)	(88.1)	11.9

Figure 2 plots crop production over the seven years between 2007 and 2013, which reveals the following picture:

- The varieties from Morocco and Algeria recorded the highest crop production/tree (4–13 kg);
- The highest rates were recorded for 'Noukal' (12.84 kg), followed by 'Meslala' (9.11 kg) and 'Picholine marocaine' (8.04 kg);
- The varieties from Lebanon, Libya and Syria recorded the lowest rates (< 3.35 kg);

- There are considerable differences between the trees of all the varieties (> 68%);
- The differences in crop production capabilities are influenced by the geographical and environmental conditions, which explains why the Maghrebi varieties gave higher yields and the Middle Eastern varieties gave lower ones. The Maghrebi countries have a similar Mediterranean and semi-arid climate, which is why the Moroccan and Algerian varieties show the ability to adapt to the Tunisian climate. In contrast, the semi-humid and humid climate in the Middle East hampers the acclimatisation of varieties from these countries to the conditions in Tunisia.

The large variation observed in all the varieties reflects a tendency towards pronounced alternate bearing since the collection is managed under rainfed conditions and is planted at a high density.

Many local and foreign varieties held in the Bank were used in the programme for the genetic improvement of the 'Chemlali de Sfax' variety. The hybridisation of the local variety with the Arab varieties is reported in Table 3. This clearly shows that hydridisation of the Tunisian 'Chemlali de Sfax' variety was focused on reciprocal crosses with 'Sigoise' from Algeria and 'Souri' from Lebanon and finally generated 54 and 59 hybrids, respectively. It seemed logical to choose these two varieties owing to the balanced fatty acid composition of their oils which contain more than 70% oleic acid and less than 12% palmitic acid (Zarrouk *et al*, 2009; Arslan, 2012). Hybrids obtained from these two varieties can lead to the selection of new improved varieties with a better fatty acid composition than 'Chemlali de Sfax'.

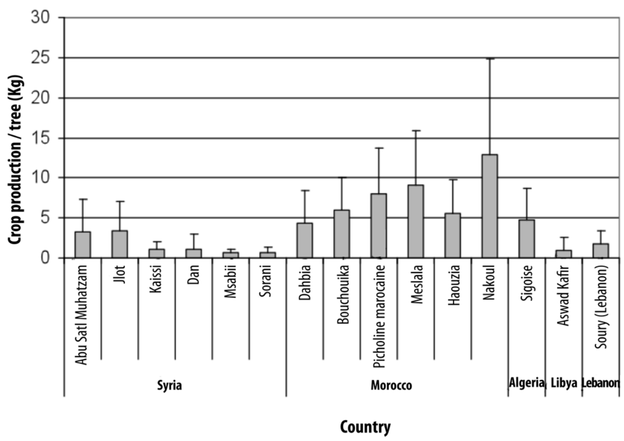

Figure 2: Crop production/tree of the Arab varieties held at the Boughrara Bank

Table 3. Results of crossbreeding with 'Sigoise' and 'Soury' (Lebanon) varieties

Number of hybrids	Varieties
42	Chemlali/Sigoise
12	Sigoise/Chemlali
17	Chemlali/Soury
42	Soury/Chemlali

Conclusions

There are few Arab varieties in the Boughrara Olive Germplasm Bank (Sfax), a fact that reflects the poor level of cooperation among Arab countries in the field of olive growing. Such a situation contributes to the loss of genetic olive resources and divests the Arab countries of the opportunity to harness the excellent traits of some Arab varieties. It is therefore crucial to set up collaborative projects for the exchange of varieties among Arab countries and the study of varietal characteristics.

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Evaluation of the oxidative stability of blends of 'Arbequina' olive oils with other monovarietal olive oils

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Abstract

Like elsewhere in the Mediterranean, the olive oil sector is one of the strategic branches of the Moroccan economy owing to its social and economic significance. This research entailed evaluation of the oxidative stability of olive oils made up of a blend of 'Arbequina' olive oil with 'Arbosana' and 'Koroneiki' monovarietal oils known for their high content of natural antioxidants (phenols and tocopherols) and their superior oxidative stability compared with 'Arbequina' oil. The monovarietal oils produced from the 'Arbequina', 'Arbosana' and 'Koroneiki' varieties, which have recently been introduced under intensive cultivation in the eastern region of Morocco, underwent physico–chemical characterisation to determine quality criteria, natural antioxidant content, fatty acid composition and triacylglycerol profile. The Rancimat test* was performed to assess the oxidative stability of these monovarietal oils and their three-variety blends. The oxidation tests were performed on five freshly prepared blends **(A)** of the three varieties – 'Arbequina'/'Arbosana'/'Koroneiki' – according to the following volume ratios: $\mathbf{A_1}$: 60/30/10; $\mathbf{A_2}$: 60/20/20; $\mathbf{A_3}$: 60:10:30; $\mathbf{A_4}$: 50:25:25 and $\mathbf{A_5}$: 40:30:30. The test results show that blends $\mathbf{A_4}$ and $\mathbf{A_5}$ displayed the best oxidative stability, recording respective values of 72.67 h and 75.42 h. These results are comparable to those obtained for 'Arbosana' monovarietal oil (75.42 h), which is considered to be relatively stable. Hence, blending is an excellent tool for enhancing oils produced from varieties which, despite their excellent initial quality and their organoleptic attributes, are handicapped by their poor stability, as is the case of 'Arbequina' oil.

Key words

Eastern region of Morocco, 'Arbequina', 'Arbosana', 'Koroneiki', monovarietal olive oil, oil blend, natural antioxidants, oxidative stability.

*The Racimat test is not an official IOC method

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Introduction

World consumption of olive oil continues to climb as more and more new consumers across the globe incorporate it into their diet. Until now Spain and Italy have been the world's top two olive oil producers but this panorama has started to change since countries in the Maghreb like Morocco and Tunisia embarked on olive growing expansion programmes. This orchard expansion has been accompanied in recent years by big changes in olive cultivation, olive harvesting and olive oil processing prompted by the introduction of new varieties, olive harvest mechanisation and increasing mill automation. In Morocco, new varieties of olive such as 'Arbequina', 'Arbosana' and 'Koroneiki' are being introduced specifically for olive oil production. Originating in Catalonia, 'Arbequina' is one of the chief varieties of olive cultivated in Spain (Tous and Romero, 1992; Tous *et al.*, 1997; Tous *et al.*, 2001; Rallo, 2002). It is also being planted increasingly more in olive orchards on the southern shores of the Mediterranean, mainly in Tunisia and Morocco (Ait-Hmida, 2010; Mahhou *et al.*, 2011; Rkhis *et al.*, 2010; El Mouhtadi *et al.*, 2014). Olive farmers choose 'Arbequina' for several reasons: it is suited to the soil and climatic conditions in high density orchards in the southern Mediterranean region (Boulouha, 2006), its entry into production is early and it has a high oil content compared with native varieties (Rkhis *et al.*, 2010; Mahhou *et al.*, 2011; El Mouhtadi *et al.*, 2014). The oil produced from 'Arbequina' olives is very fruity, smooth and aromatic; it is not bitter and has virtually no pungency. On the downside, its oxidative stability is poor because of its low content of natural antioxidants and its high level of polyunsaturated fatty acids (Terouzi *et al.*, 2010; Gharby *et al.*, 2012; Mansouri *et al.*, 2013).

This research focused on the characterisation of the oils obtained from three varieties – 'Arbequina', 'Arbosana' and 'Koroneiki' – recently introduced in the eastern region of Morocco under super-intensive, irrigated olive cultivation. After undergoing physico–chemical characterisation, the 'Arbequina' oils were blended with 'Arbosana' and 'Koroneiki' oils, which are known for their high natural antioxidant content, and the different blends were tested for their oxidative stability using the Rancimat test. The objective was to achieve a blend combining good organoleptic attributes and better oxidative stability. If this methodology were to be mastered by oil mills, it would no doubt help them to expand their range of commercial products by creating new brands of monovarietal blends to satisfy the growing diversity of consumer tastes.

Materials and methods

Plant material

The samples of olive oil studied were monovarietal oils produced from 'Arbequina', 'Arbosana' and 'Koroneiki' olives in the 2013/14 crop year. The olives were grown in irrigated, super-intensive orchards planted at a density of 1 300 trees/ha. The trees were 6–7 years old and were cultivated in the same soil and climatic conditions and received the same cultural care. The olives were crushed and the oil was stored and bottled at the on-farm mill.

Quality criteria

Free acidity (% C18 :1), peroxide value (PV, meq/kg) and the specific coefficients of extinction in ultraviolet at 232 nm (K_{232}) 270 nm (K_{270}) and ΔK measured by spectrophotometry were determined according to the methods recommended by the International Olive Council and specified in the EU regulation on the characterisation of olive oils (EEC, 2003).

Total phenols

The phenolic compounds were extracted according to the method described by Ollivier *et al.* (2004). Total phenol content was determined by the Folin-Ciocalteu method using caffeic acid as the standard. The results were expressed in milligrams of caffeic acid/kg of olive oil.

Tocopherols

Alpha-tocopherol (the majority compound) was determined by HPLC chromatography using a diode array detector according to the amended AOCS method (1989). Separation was performed on a silica column using hexane/isopropanol (99/1, v/v) as the mobile phase at a flow rate of 1 mL/min. An alpha-tocopherol standard was used for identification purposes and a calibration curve for quantification.

Fatty acid composition

The methyl esters of the fatty acids were analysed by gas chromatography using a flame ionisation detector (FID). Separation was performed on an HP-5880A capillary column (25 m × 0.25 mm, 0.25 µm). The temperature of the FID detector was 250 °C. Optimal separation was obtained under the following conditions: initial oven temperature of 50 °C, increased to 150 °C at a rate of 30 °C/min, and then to 240°C at a rate of 4 °C/min and maintenance at this temperature for 10 minutes. An injection volume of 1µL was used (splitless mode).

Triacylglycerol (TAG) composition

TAG composition was determined by HPLC according to the amended method (Abaza *et al.*, 2002):

10 μL of the oil in acetone (10%, P/V) were fractionated in a Shimadzu CBM 20A HPLC chromatograph (equipped with a refractive index detector, RID, 10A). Isocratic separation was performed with the aid of an ODS C18 apolar reverse-phase column (250 mm × 5 mm, 5 μm). The mobile phase was a mix of two solvents, acetone and acetonitrile (63.6/36.4 V/V), at a flow rate of 1 mL/min.

Oil oxidative stability

Oxidative stability was evaluated by the Rancimat method (Gutiérrez Rosales, 1989). The Rancimat induction time (expressed in hours) was determined using a Metrohm Rancimat 743 with a 3 g test sample of oil at an air flow of 15 l/h and a temperature of 101 °C.

Blending

The three varietals ('Arbequina', 'Arbosana' and 'Koroneiki') were blended in varying volume/volume percentages as shown in Table 1. The 'Arbequina' oil was always predominant in the blends (at least 40% V/V).

Table 1: Identification of the different volume/volume blends (A1, A2, A3, A4, A5) of 'Arbequina', 'Arbosana' and 'Koroneiki' oils produced in the eastern region of Morocco in the 2013/14 crop year.

Blend code	% monovarietal oil		
	% Arbequina	% Arbosana	% Koroneiki
A_1	60	30	10
A_2	60	20	20
A_3	60	10	30
A_4	50	25	25
A_5	40	30	30

Statistical analysis

The results reported are the means of triplicate analyses and are given as means ± standard deviation. Significant differences between the means were determined by analysis of variance using SPSS statistics software (SPSS 20, USA).

Results and discussion

Quality criteria

Table 2 reports the results of the basic physico–chemical analyses performed on the monovarietal olive oils. These show that the quality criteria, namely free acidity, peroxide value and specific extinctions (K_{232}, K_{270} and ΔK) were distinctly lower than the limits recommended for extra virgin olive oils (EVOO) in the IOC trade standard applying to olive oils and olive pomace oils (IOC, 2013).

Table 2: Quality criteria of monovarietal 'Arbequina' 'Arbosana' and 'Koroneiki' oils produced in the eastern region of Morocco in the 2013/14 crop year

Quality criteria	Variety			EVOO*
	Arbequina	Arbosana	Koroneiki	
Acidity (% C18:1)	0.24 ± 0.02^{ab}	0.21 ± 0.04^{a}	0.29 ± 0.04^{b}	≤ 0.8
Peroxide value	6.78 ± 1.16^{a}	9.08 ± 0.69^{ab}	10.89 ± 1.13^{a}	≤ 20
K_{232} K_{270}	0.10 ± 0.00^{a} 1.66 ± 0.06^{b}	0.12 ± 0.00^{b} 1.73 ± 0.03^{b}	0.15 ± 0.01^{c} 1.50 ± 0.03^{a}	≤ 0,22 ≤ 2.5
ΔK	0.002 ± 0.0001^{a}	0.006 ± 0.0003b	0.007 ± 0.0004b	≤ 0.01

Different letters (a-c) on the same line indicate significant differences.
*Extra virgin olive oil (IOC, 2013).

Fatty acid profile of the monovarietal oils

Fatty acid composition is central to the nutritional and organoleptic quality of olive oil. Olive oil is made so original and healthy by its high content of monounsaturated fatty acids, amongst which oleic acid can account for as much as 83%. Several factors such as degree of fruit ripeness, climate or variety affect the fatty acid composition of olive oil (Garcia *et al.*, 1996; Judde, 2004, Pardo *et al.*, 2007). The data given in Table 3 show that the fatty acid composition of the oils tested complied with the requirements of the IOC trade standard (IOC, 2013).

Table 3: Fatty acid composition of the 'Arbequina', 'Arbosana' and 'Koroneiki' olive oils produced in the eastern region of Morocco in the 2013/14 crop year

Fatty acid (%)	Monovarietal olive oil			EVOO*
	Arbequina	Arbosana	Koroneiki	
Myristic acid	0.02 ± 0.00[b]	ND[a]	ND[a]	<0.03
Palmitic acid	16.42 ± 0.01[c]	14.84 ± 0.01[b]	12.08 ± 0.39[a]	7.5 - 20.0
Palmitoleic acid	1.71 ± 0.01[c]	1.35 ± 0.01[b]	0.66 ± 0.09[a]	0.3 - 3.5
Margaric acid	0.10 ± 0.00[b]	0.17 ± 0.00[c]	0,04 ± 0,01[a]	≤ 0.3
Margaroleic acid	0.22 ± 0.00[b]	0.36 ± 0.00[c]	0.08 ± 0.01[a]	≤ 0.3
Stearic acid	1.88 ± 0.01[a]	2.21 ± 0.01[ab]	2.27 ± 0.32[b]	0.5 - 5.0
Oleic acid	65.67 ± 0.02[a]	73.10 ± 0.01[b]	77.15 ± 0.2[c]	55.0 - 83.0
Linoleic acid	12.54 ± 0.02[c]	6.40 ± 0.00[b]	6.26 ± 0.11[a]	55.0 - 83.0
Alpha-linolenic acid	0.56 ± 0.00[a]	0.65 ± 0.00[b]	0.63 ± 0.05[b]	3.5 - 21.0
Arachidic acid	0.40 ± 0.01[a]	0.44 ± 0.00[a]	0.40 ± 0.07[a]	≤ 1.0
Gadoleic acid	0.29 ± 0.01[a]	0.30 ± 0.00[a]	0.26 ± 0.05[a]	≤ 0.6
Behenic acid	0.13 ± 0.01[a]	0.17 ± 0.00[b]	0.13 ± 0.02[a]	≤ 0.4
ΣSFA	19.02 ± 0.02[c]	17.83 ± 0.01[b]	14.93 ± 0.04[a]	≤ 0.2
ΣMUFA	67.89 ± 0.02[a]	75.11 ± 0.01[b]	78.15 ± 0.12[c]	
ΣPUFA	13.09 ± 0.02[c]	7.05 ± 0.00[b]	6.89 ± 0.08[a]	
O/L ratio	5.24 ± 0.01[a]	11.41 ± 0.00[b]	12.33 ± 0.21[c]	

Different letters (a-c) on the same line indicate significant differences.
SFA: saturated fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids; O/L: oleic/linoleic ratio. *Extra virgin olive oil, IOC, 2013.

Significant differences were observed between all the varieties studied ($p<0.05$) for all the parameters. Several authors have documented the heavy effect of variety on the fatty acid profile of olive oils. The oils produced from the 'Arbosana' and 'Koroneiki' varieties had comparable fatty acid profiles characterised by high levels of oleic acid (77.15 and 73.10%, respectively) compared with the 'Arbequina' oil (65.67%) and relatively low levels of palmitic acid (12.08 and 14.84% respectively) and linoleic acid (6.26 and 6.40%, respectively). The fatty acid profile of the 'Arbequina' oil differed from that of the other two varieties in that it recorded high levels of palmitic acid (16.42%) and saturated fatty acids (SFA: 19.02%), a low level of monounsaturated fatty acids (MUFA: 67.89%) and the lowest oleic/linoleic acid ratio (O/L) owing to its low content of oleic acid (65.67%) and its high content of linoleic acid (12.54%), which are major fatty acids.

Composition of triacylglycerol molecular species in olive oils

Nine different molecular species of triacylglycerols (TAGs) were distinguished in the olive oils tested: OOO, POO, LOO, LPO, SOO, POP, LOL, LPL and POLn (Figure 1). Listed by descending order of quantity, they are triolein (OOO), accounting for almost half of the TAGs in the 'Koroneiki' oil (48.02%) but only one-third in the 'Arbequina' oil (31.51%); dioleopalmitin (POO) with levels of 20.45 to 29.80%; dioleolinolein (LOO) with rates from 10.32 to 16.97% and palmitooleolinolein (LPO) with levels between 4.20 and 11.10%. These four major species of TAG account on their own for more than 91% of the total TAGs; the rest represent small quantities ranging from 0.5 to 4%. These results concur with those reported for olive oils produced from these varieties in Tunisia (Abaza *et al.*, 2002). The predominance of four molecular types of TAGs with at least one oleate (OOO, POO, LOO, POL) is linked to the fatty acid composition of the oil, characterised by its high oleic acid content.

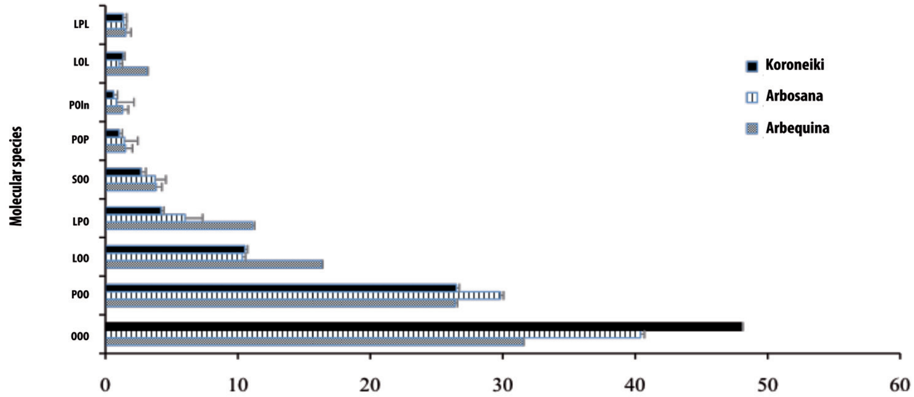

Figure 1: Composition of molecular species of TAGs of monovarietial 'Arbequina,' 'Arbosana' and 'Koroneiki' olive oils produced in the eastern region of Morocco in the 2013/14 crop year (P: palmitate; S: stearate; O: oleate; L: linoleate; Ln: linolenate)

Natural antioxidant content and oxidative stability of monovarietal oils and monovarietal blends

Virgin olive oil is virtually the only oil to contain notable amounts of natural antioxidants (phenols and tocopherols). Besides lending olive oil its distinctive taste – both fruity and bitter – phenols are believed to be largely responsible for its oxidative stability (Boskou *et al*., 1996; Mansouri *et al*., 2013). The phenol and tocopherol content of olive oil, and hence its oxidative stability, is variety-dependent (Table 4). All the oils tested contained considerable amounts of phenolic compounds. The 'Koroneiki' olive oil had the highest phenol content (566.30 mg kg^{-1}) and the best oxidative stability (102.44 h). In contrast, the 'Arbequina' oil recorded the lowest content (286.51 mg kg^{-1}), which translates into poor oxidative stability (53.78 h). Hence, a clear correlation was observed between natural antioxidant content (chiefly phenols) and Rancimat oxidative stability; this finding concurs with results published in the literature (Tanouti *et al*., 2011; Grati Kammoun and Laroussi, 2013).

Table 4: Natural antioxidant content and evaluation of the oxidative stability of monovarietal olive oils produced from 'Arbequina', 'Arbosana' and 'Koroneiki' olives in the eastern region of Morocco in the 2013/14 crop year

	Monovarietal olive oils		
	Arbequina	Arbosana	Koroneiki
Total phenols (mg kg^{-1})*	286.51 ± 5.63[a]	454.8 ± 11.87[b]	566.30 ± 8.87[c]
Alpha-tocopherol (mg kg-1)	322.36 ± 13.54[b]	460.07 ± 15.16c	344.58 ± 11.54b
Oxidative stability (hr)	53.78 ± 1.81[a]	78.81 ± 0.90[b]	102.44 ± 0.19[c]

Different letters (a-c) on the same line indicate significant differences.
*Polyphenol content is expressed in milligrams of caffeic acid per kilogram of oil.

Rancimat evaluation of the oxidative stability of the monovarietal oils (Table 4) revealed significant between-variety differences ($p<0.05$). Variety is therefore a factor that clearly influences oil stability. Concomitant comparison of the oxidative stability, phenol content and fatty acid composition of the three varieties shows that the phenol-rich oils ('Koroneiki' and 'Arbosana') were more stable in oxidative terms. Besides having a very high content of these antioxidant compounds, they had low levels of polyunsaturated fatty acids and a high MUFA/PUFA ratio. The higher the PUFA content of the oil, the more susceptible it is to attack from oxidation reactions. Conversely, phenolic compounds limit such reactions through their antioxidant effect (by free radical scavenging). The combined effect of low PUFA content and high phenol content is believed to be the reason for the great stability of olive oil and its low peroxide value (Allalout *et al*., 2009; Aparicio *et al*., 1999; Baccouri *et al*., 2008; Bendini *et al*., 2007; Boselli *et al*., 2009, Gómez-Alonso *et al*., 2002; Gutierrez *et al*., 2001; Mansouri *et al*., 2013).

High phenol content is definitely involved in oil resistance to oxidation but it also plays a part in its organoleptic properties. Several studies (Ollivier et *al*., 2004) have reported a close relationship between high polyphenol and ortho-diphenol content and the bitter, astringent and pungent tastes in olive oil.

With the assistance of an olive oil mill in the region, we prepared blends of the three monovarietal oils (Table 1). 'Arbequina' oil accounted for at least 40% (V/V) of the blends. Blending 'Arbequina' with 'Arbosana' and 'Koroneiki' gives oils that are highly rated for their sweetness and rich fruity aromas and which have a high content of phenols and tocopherols that makes them more resistant to oxidative instability. Comparison of the Rancimat induction times of the blends (Table 5) and the 'Arbequina' monovarietal oil (Figure 2) clearly shows the effect of blending in correcting the poor oxidative stability reported for oils produced from the 'Arbequina' variety.

Table 5: Oxidative stability of three-variety blends of monovarietal 'Arbequina', 'Arbosana' and 'Koroneiki' olive oils produced in the eastern region of Morocco in the 2013/14 crop year

	Three-variety blends of monovarietal olive oils				
	A_1	A_2	A_3	A_4	A_5
Oxidative stability (h)	63.22 ± 1.09[a]	67.19 ± 1.14[b]	69.28 ± 1.02[b]	72.67 ± 2.2[c]	75.42 ± 0.67[d]

Different letters (a-c) on the same line indicate significant differences.

The better oxidative stability of the blends of 'Arbequina' with 'Arbosana' and 'Koroneiki' is certainly due to the increase in their phenol content and decrease in their PUFA content. It is common knowledge that the last two oils contain a large quantity of natural antioxidants and small amounts of PUFAs (see Table 3). Figure 2 shows that the oxidative stability of the blends (going from A1 to A5) was distinctly better, owing to the reduction in the percentage share of 'Arbequina' oil. Significant differences were detected between the different blends ($p<0.05$): the most stable blend proved to be A5 (75.42 h), which contained the least amount of 'Arbequina' oil. Although blends A1, A2 and A3 contained the same percentage of 'Arbequina' (60%), they varied in oxidative stability. Stability appears to depend above all on the proportion of 'Koroneiki' oil. Hence, blends A2 and A3 containing 20 and 30% 'Koroneiki' oil respectively were more stable (with Rancimat induction times of 67.19 h and 69.28 h, respectively) than blend A1, which contained only 10% 'Koroneiki' oil and recorded an induction time of 63.22 h.

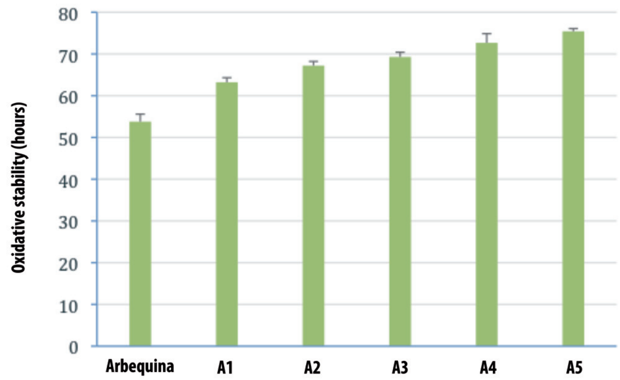

Figure 2: Changes in the oxidative stability of 'Arbequina' olive oil and of blends of such oil with 'Arbosana' and 'Koroneiki' monovarietal olive oils.

Conclusions

Olive oil oxidative stability is basically variety-dependent. It is closely linked to the natural antioxidant content (phenols and tocopherols) and MUFA/PUFA ratio of the oil. These parameters have to be taken into account to produce quality blends. The recommendation is to limit the amount of poor stability oil (the case of 'Arbequina') to less than 50%; the rest should be made up of oils that help to lower the PUFA content and raise the natural antioxidant content of the resultant blend. This would help to ensure better control of autoxidation and to preserve the organoleptic attributes of the blends. In this research, the improved oxidative stability achieved on blending 'Arbequina' with other oils helped to preserve and enhance its sensory properties, at least partially. Blending 'Arbequina' oil with two or three other monovarietal oils – "Arbosana', 'Koroneiki' and 'Picholine' – is one solution for counteracting its poor resistance to oxidation. It is also a way of responding to market needs by creating new brands of olive oils.

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Research, innovation and transfer in the olive oil sector in Spain: an analysis based on in-person expert panels

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Abstract

The first objective of this research was to obtain a consensual picture of research, development, innovation and transfer issues and priorities in the national research, development and innovation system (RDI) relating to the olive oil sector in Spain. A second objective was to design a structured series of strategic recommendations to improve that system. The results obtained from three in-person expert panels applied a sequence of social research techniques based on Metaplan methodology were analysed. *Discussion group* and *strategic participation workshop* techniques were employed to achieve these objectives. The three panels broached the following broad areas of knowledge: (i) olive growing and olive and olive oil by-products; (ii) olive oil technology, health and new products; and (iii) agro-food social sciences. The experts concluded that there was a pressing need to remedy the current general lack of innovation and knowledge transfer from the national system to businesses and farmers. They also agreed on the need to broach RDI activities from interdisciplinary and transdisciplinary angles.

Key words:

Research, innovation, knowledge transfer, discussion groups, strategic participation workshops, olive oil, Spain.

Introduction and methodology

The national RDI system in olive growing and olive oil has made great strides forward in Spain, particularly so in the last three decades, in a broad number of areas of knowledge in consonance with their economic and territorial importance; however, there is still a significant shortfall in knowledge and innovation transfer to the national olive and olive oil sector.

One of the prime arguments in favour of boosting RDI in olive growing and olive oil production in Spain is the pressing need to improve value aggregation in this sector where structural changes are occurring in the value chain and international consumption. Furthermore, the lack of organisational and business innovation in the Spanish olive oil sector calls for urgent incentives to transfer and disseminate knowledge to farmers and companies. Other factors explaining the need to drive the national RDI system include the changes in the new land functionality of the sector and its role in rural development or the emerging social awareness of food safety, health, environment and food issues.

This article reports the outcome of three in-person expert panels aimed at obtaining a consensual overview of research, development, innovation and transfer issues and priorities in the national RDI system relating to the olive and olive oil sector in Spain, as well as a structured series of strategic recommendations for improving that system. This outcome is part of the results of the research project[1] reported by Sanz Cañada *et al* (2012 a), the purpose of which was to define and prioritise the lines of research and innovation that should be strengthened in Spain's RDI[2] system. Each of the three panels addressed the following broad areas of knowledge: (i) olive growing and olive and olive oil by-products; (ii) olive oil production, health and new products; and (iii) agro-food social sciences.

The methodology for the whole project entailed a sequence of three consecutive phases, the second of which is the subject matter of this article (Figure 1). The data collected in the first phase in which 86 lines of research and innovation were identified and defined in lengthy, semi-structured interviews with experts was the starting point for the second phase.

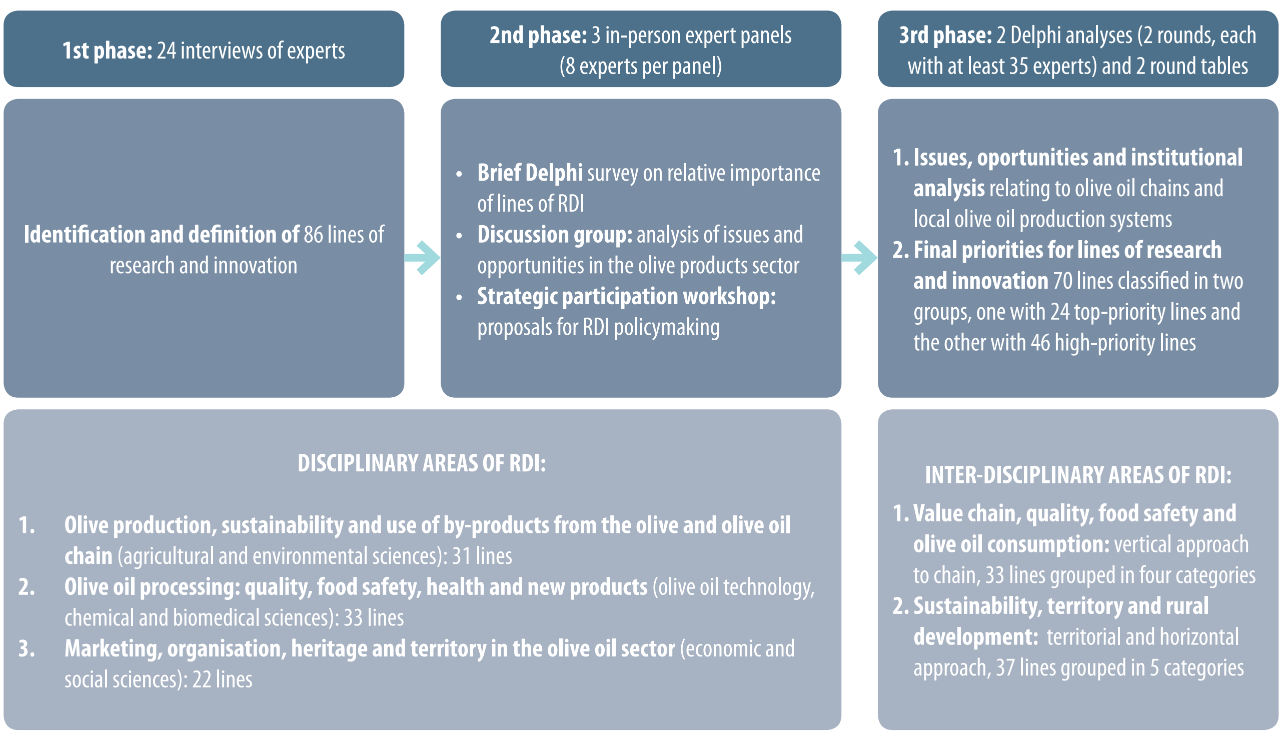

Figure 1: Methodology for the analysis of research and innovation priorities, issues and opportunities in the olive oil sector in Spain

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[1] ALENTA Technological Platform for Olive Growing. Technological Platform Subprogramme (INNFLUYE) of the National RDI Plan. Ministry of Science and Innovation: 2010–2011. Coordinated by the Citoliva Foundation with the participation of the Spanish National Research Council (CSIC)..

[2] Sanz-Cañada et al (2012 b) is another publication generated by this project. Very little research has been conducted on the olive and olive oil RDI system in Spain, although the paper by Sayadi *et al.* (2012) on Andalusia is noteworthy.

In the second phase, three in-person expert panels were applied the following mixed methods social research techniques (Johnson *et al.,* 2007; Teddlie and Tashakkori, 2009): a brief Delphi survey[3], a discussion group and a strategic participation workshop based on *Metaplan* methodology (Schnelle and Stoltz, 1987; Oakley, 1991), for which there has to be a maximum of eight experts per panel. This article reports the chief findings of the discussion groups and strategic participation workshops held by the three panels.

The experts selected for the first two phases of the project included university researchers and teaching faculty, as well as representatives from business, industry associations, institutions and the public administration, although in the last case the representatives took part as experts as opposed to in their official capacity. An attempt was made to strike a balance in the composition of each panel according to the profiles of the experts (Table 1).

The aim of the discussion groups was to detect the chief points of consensus and controversy when identifying problems and priorities in research, development, innovation and knowledge transfer[4]. Each lasted an average of five hours. The methodological design of the groups was meant to encourage the convergence of participants' perceptions or the emergence of lines of dissenting opinion and to facilitate the collection of qualitative data. Through interactive dialogue, the experts took a prospective approach in that they not only noted the problems facing the sector but also assessed the feasibility of different initiatives. The discussion groups were focal in nature and featured a questionnaire with semi-open questions and a moderator who played an active part in leading the group, which was especially evident when facilitating consensus (Greenbaum, 1999).

The objective of the strategic participation workshops was to construct a consensus-based set of strategic

Table 1: Panel composition by expert profile

	EXPERT PROFILE	Nr experts
PANEL 1: Innovation in olive production, sustainability and use of by-products from the olive and olive oil chain	1. Plant material, varieties and new olive growing	2
	2. Cultivation systems: erosion, irrigation and crop protection	2
	3. Biodiversity, integrated production and organic olive growing	2
	4. Use of waste from the olive and olive oil chain	2
PANEL 2: Oil processing technologies: quality, food safety, health and new products	5. Innovation in quality olive oil production and sensory methods	2
	6. Food safety in the olive oil chain	2
	7. Olive oil and health	2
	8. New products derived from olives and olive oil	1
	9. Innovation in information technology and traceability systems	1
PANEL 3: Marketing, organisation, heritage and territory in the olive oil sector	10. Olive oil marketing and consumption	2
	11. Multi-functionality, landscapes and natural and cultural heritage	3
	12. Cooperatives and marketing (second-tier level)	2
	13. Designations of origin and quality certification institutions	1

[3] The experts were requested to complete the Delphi questionnaires twice, i.e. before and after holding the discussion group. Under each questionnaire heading they had to use a 1 to 5 scale to appraise the RDI identified on the basis of the analysis of the interviews. The object was for participants to ponder on the questions beforehand and then to incorporate the consensual points that subsequently emerged from the discussion group.

[4] It should be pointed out that this is not a discussion group in the classic sense because it does not comply with the strict requisite of such techniques, namely that the members of the group must not know each other, since this is practically impossible in the national community of experts on prospective topics of research and innovation.

guidelines for improving the national RDI system. The card visualisation technique was used where participants were asked a number of questions to which they had to write down their answers briefly on a card[5]. Once the cards had been completed and read out, they were pinned on a board. Participants then separated the different RDI actions into clusters by topic and objective and assigned each one a name.

The set of research techniques employed is not meant to give an exhaustive list of RDI topics and lines of work but an overview of some of the chief debating points and recommendations for taking action on the issues and priorities in research, innovation and transfer in the Spanish olive and olive oil sector. The interactive dialogue that took place among the experts generated a wealth of intelligence on the different topics discussed.

The next section reports the results obtained in the three expert panels, which in turn encompassed 11 subthemes. The main consensus points are outlined together with any controversies and the main lines of discussion. The arguments are illustrated by textual quotes of statements made during the discussion groups, as well as of the strategic recommendations for action in the national RDI system (Figures 2–11).

Analysis of expert panel results

Innovation in olive production, sustainability and use of by-products from the olive and olive oil chain[6]

Soil erosion and degradation

Erosion is a pressing problem in a broad section of Spain's olive orchards, especially those on steep land, and is part and parcel of the wider issues of soil degradation and management. The consensus among the experts was that it is the chief environmental problem in olive growing in Spain. They confirmed that the bulk of research in Spain has focused on quantifying erosion rather than on offering concrete solutions to remedy it:

"Much of what has been done has been to continue quantifying the problems rather than offering solutions. I think there is a clear-cut difference between the progress made on the production front and the environmental solutions put forward."

The experts also stated that few reliable data are available on erosion in terms of large-scale and catchment areas because the trials conducted so far have been very limited in number or very localised compared with the severity, variability and extent of erosion in Spanish olive orchards. Representative interdisciplinary research needs to be carried out on a territorial scale and models need to be validated for the assessment of soil losses:

"Very few trials have been conducted to measure soil erosion and soil erosion impact in olive growing and those that have been carried out have been very local and basically confined to three or four sites in Andalusia… It is very hard to fine-tune management systems and determine actual nutrient and herbicide losses outside the specific conditions of those trials… Extrapolation is very hard because very little territorial information is available."

The experts also considered it necessary to research *soil erosion* and *degradation* more than erosion and soil loss:

"Not only is soil loss occurring in some olive orchards ….. there are some orchards where the soil has already reached a very severe stage of degradation that requires priority action and others where it has not yet reached such a critical condition. No systematic approach has been taken to this question."

The experts emphasised that the innovation and transfer work of the research community should include offering clearer management guidelines to olive farmers to resolve these problems. In particular, one of the main alternatives for curbing soil erosion and degradation is to grow *plant covers* adapted to each agroecosystem[7], which also help to increase water application efficiency:

"Surprisingly, we have found many orchards where plant cover is applied as green manure in the springtime and the soil is excellent … If this kind of approach were to be applied a little further, it could help us to refine our management systems."

The experts also thought it advisable to extend plant covers as widely as possible in rainfed orchards, not just in orchards on slopes with a gradient of more than 10% as is the case in Andalusia since 2010 where it is a cross-compliance requirement for direct payments under the

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[5] Each question referred to each of the research and innovation clusters. For instance, one of the questions was: "What measures could be designed to develop priority lines of RDI in olive irrigation in order to enhance water use efficiency?".

[6] Bibliographical references on topics such as olive growing and sustainability and organic and integrated cultivation systems include Barranco *et al.* (2008), Gómez Calero (2010), Guzmán Casado (2011), Pajarón (2007) and Saavedra and Pastor (2002).

[7] See Rodríguez-Lizana *et al.* (2007).

Common Agricultural Policy (CAP). Much research and experimental work remains to be done, for instance to determine the most suitable plant cover species for specific soils and climates depending on factors such as how they compete for water resources and minerals and their productive capabilities. It is important to identify the cover crop management system suited to the different agro-ecosystems and to relay the results to farmers.

Lastly, the experts highlighted two new avenues of research and innovation: mechanical crop cover management and the biofumigant properties of specific plant covers when ploughed into the ground, which could therefore help to control verticillium wilt.

Figure 2 outlines the results of the strategic participation workshop on soil erosion and degradation

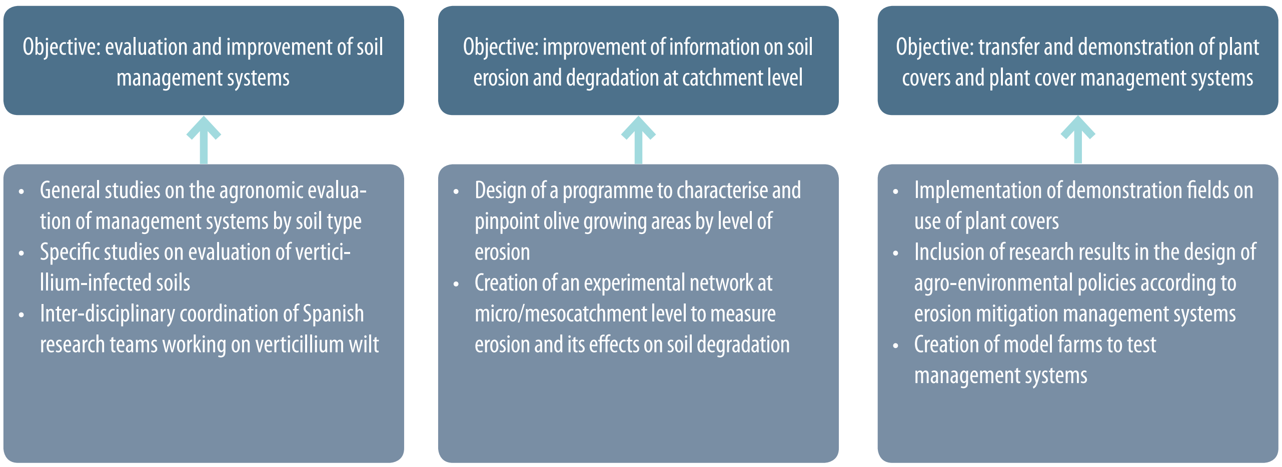

Figure 2: Strategic recommendations on soil erosion and degradation

Use of residue and by-products from the olive and olive oil chain

Two main types of olive product waste are starting to have applications in ***soil replenishment***, namely pruning debris and compost made from two-phase olive pomace (called *alperujo* in Spanish). These solutions are to be recommended, particularly in steep olive orchards owing to their special problems of soil erosion and degradation, and should therefore be disseminated and transferred.

It has been demonstrated that *pruning debris* gives more than acceptable results when used to improve the soil; however, in the major olive producing areas there is a surplus of pruning material, the transportation of which usually poses problems of cost-effectiveness. Hence, improved mechanisation of pruning debris collection using efficient machinery that is adapted to steep land and that has a minimal environmental impact is decisive when it comes to determining whether or not pruning debris can be reused. Such technological advances have to come from the machinery manufacturing industry. Also, research is needed on biomass soil degradation according to the environmental conditions as well as on the best management practices for using residue on different soil types in order to gain more insight into the sustainability of pruning residue:

"Pruning debris clearly improves soil properties ….. Given the degradation of orchard soils, it is essential to combine this practice with composting or other practices. On the other hand, when there is a surplus of pruning residue, as can occur in major producing areas, it may prove even counterproductive to leave the residue on the ground because this could give rise to allelopathic substances that could have a negative impact on the balance in the orchard."

Two-phase pomace is composted primarily for use as organic soil amendment and fertiliser, although with some limitations. Here again high transportation costs are the chief problem facing RDI: it is only economically worthwhile for olive growers to apply it when the orchards are near the composting plant. The production of organic fertilisers from two-phase pomace face the same problems of cost effectiveness, for exactly the same reasons.

Research in Spain is largely oriented at mixing two-phase pomace with other types of low-cost residue that are resistant to soil biodegradation in order to make organic fertilisers enriched with ligno-cellulose organic matter. The limiting factor is that this type of fertiliser lacks nitrogen but when it is nitrogen-enriched its pH increases too much; this is a very interesting problem for basic research.

Olive pomace and *olive stones* are the chief inputs[8] for ***energy generation*** from olive oil biomass. Although this technology has recently been spreading, specific avenues of research still need to be followed up. For instance, it would be advisable to make the current technologies more energy efficient as well as to research into gasification (more combustion efficient) and to resolve the environmental problems posed by olive stone drying.

Some technological advances have been made in the reuse of *pruning debris* as a source of energy but they are not yet fully feasible. According to the experts, the main problems are likewise associated with the logistics of pruning residue collection. For this activity to be profitable, the transportation costs of such a bulky raw material need to be optimised and clear factory location criteria need to be established:

"It is important for research to be conducted on the reuse of olive growing by-products for agricultural and energy purposes. Here, logistics is the key issue because re-use will be difficult unless it is cost-effective for olive farmers to transport the by-products."

Figure 3 outlines the results of the strategic participation workshop on the re-use of waste and by-products from the olive and olive oil chain.

Objective: improvement and fertilisation of agricultural soils

- Compilation of studies on the limitations on the spread of the use of by-products as fertilisers
- Analysis of the technical and economic feasibility of using residue and by-products for agricultural purposes
- Compilation of studies on the use of by-products as soil amendments
- Compilation of studies on the changes in the organic matter content of olive orchard soils and the need for applications of organic matter
- Analysis of the agricultural sustainability of pruning debris

Objective: production of energy and valuable compounds

- Analysis of the sustainability of pruning debris for energy purposes
- Study of the life cycle of pruning debris used as a source of energy
- Compilation of a study on the energy and economic balance of using pruning debris as biofuel
- Studies to identify high added-value (biological, pharmaceutical, etc) products in olive pomace

Figure 3: Strategic recommendations on the use of residue and by-products from the olive and olive oil chain

Organic olive growing, integrated production and biodiversity. Weed, pest and disease control

There is a consensus that the RDI system, policy making and industry should place top priority on the reduction and rational use of ***plant health products*** because of the risks they pose in terms of food safety and environmental pollution.

Herbicides have played an important part in weed control, besides facilitating harvesting and lowering costs. In point of fact, efficient weed control may lead to a 20–30% increase in crop production at lower cost. However, according to the experts, the uncontrolled application of herbicides, insecticides and fungicides has led in recent decades to major risks of soil and aquifer pollution, although the use of these products has decreased in the past five years.

They also agreed that *verticillium wilt* is possibly one of the most pressing problems in olive growing in Spain, and particularly affects superintensive irrigated orchards. Their joint diagnosis is that an interdisciplinary approach needs to be taken to verticillium wilt control in the form of a research programme involving at the very least specialists in plant pathology, cultivation systems and genetic improvement. This is warranted by the fact that accurate assessment of the importance of the different sources of propagation of the disease is not yet possible:

"The reasons have yet to be discovered. It is not yet known whether it is a natural progression of the disease due to the exchange of material or whether it is linked to an ecological imbalance in the micro-organisms in the olive orchard and other factors."

The propagation of the disease is believed to be due to a variety of causes[9], such as inappropriate nursery practices or irrigation systems, for instance when the soil is kept constantly damp around the tree trunk.

8 See Junta de Andalucía (2010).
9 See Mercado-Blanco and López-Escudero (2012).

Contaminated irrigation water or other crops planted previously in the same plot are other possible origins of the fungus. The experts also recommended driving breeding research to obtain verticillium-resistant plant material in the environmental conditions characteristic of "new olive growing".

Organic farming and ***integrated production*** are management alternatives to weed, pest and disease control. The experts explained that while organic production is practised primarily in lower yielding orchards, although it is also starting to spread to other more productive areas, integrated production is expanding to all types of olive orchards.

They considered it vital to develop alternative pest control systems in the form of integrated management methods based on the use of auxiliary insect populations. As a general recommendation, they advised maintaining farm biodiversity thresholds:

"One thing that is clear is that pest and disease control is intertwined with diversity. In many cases, simply stopping the use of plant health products makes the pest problem disappear, although not always…".

Biodiversity in olive agro-ecosystems is the sphere of olive growing sustainability in which research and innovation are perhaps lacking the most:

"In the case of environmental issues, there are several voids, one of which is definitely biodiversity research. This question has been addressed in research papers for twenty years now but when it comes to quantification, it is behind other types of environmental studies in olive growing."

The conservation of the varietal diversity of Spanish olive orchards was another subject that was mentioned[10]. Until quite recently, farmers propagated their own plants but a powerful nursery industry has grown up and now supplies all new plants, thus leading to a drastic reduction in the assortment of varieties on offer:

"Nowadays three or four varieties account for more than 95% of olive nursery sales. Traditional varieties are being replaced by others better adapted to the new form of olive growing".

The results of the participatory strategic workshop on organic olive farming, integrated production and biodiversity are given in Figure 4.

Objective: research and better understanding of organic olive farming

↑

- Study on the profitability of organic and integrated olive cultivation according to fertilisation and pest control
- Research to evaluate the environmental and economic value of organic and integrated olive growing according to the type of practice
- Studies on the energy and nutrient balance according to cultivation system
- Research on the characterisation of olive growing agro-systems

Objective: research and better understanding of biodiversity

↑

- Studies to define and standardise biodiversity scales
- Research programme to study biodiversity in the different production systems and make recommendations for biodiversity conservation
- Quantification of the carbon balance in different types of olive orchard

Figure 4: Strategic recommendations on organic olive growing, integrated production and biodiversity

Olive irrigation and enhancement of water use efficiency

From the point of view of RDI objectives, considerable progress has been made at world level in developing technologies for efficient water use. The top priority now is to provide farmers and local institutions with sustainability criteria enabling the allocation of water resources according to usage on a socio-economic and environmental basis. The proposal is therefore to give an impetus to advisory services for irrigation users:

"Water usage has to be acceptable from the social and land points of view, not just for the individual farmer… Water resources are general; by law, they belong to everyone."

Specifically, the panel concluded that deficit olive irrigation tends to give higher yields and marginal profits well above those obtained for many other crops. The experts suggested boosting cross-sectional and interdisciplinary research and including weed and soil management in water research. They also concluded that it

[10] See Rallo (2004) for an inventory of the varieties in Spanish olive orchards.

is necessary to conduct an economic and environmental appraisal of all alternative water uses on a district scale, including olive irrigation.

The outcome of the participatory strategic workshop on olive irrigation and the enhancement of water use efficiency is outlined in Figure 5.

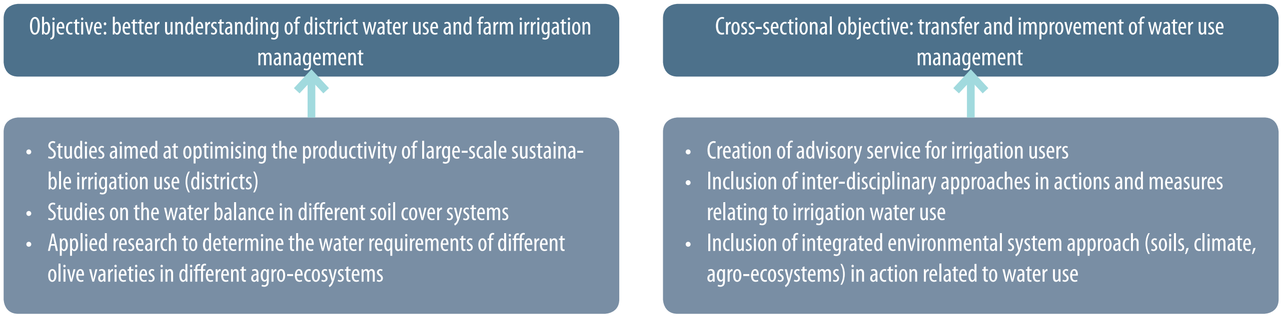

Figure 5: Strategic recommendations on olive irrigation and the enhancement of water use efficiency

Oil processing technologies: quality, food safety, health and new products

Food safety and olive oil fraud

Although modern societies are very aware of *food safety,* the panel believes that pesticide residues continue to pose a threat in the specific case of some oils in Spain. Nowadays, the effects of plant health products are known; the solution is therefore basically to transfer this knowledge. According to the specialists, the chief measure should be for olive growers and olive oil producers to be advised by agronomists who can teach them good practices. This means encouraging what are known as Integrated Production Associations (IPAs) or Associations for an Integrated Approach to Agriculture (GIAAs) where farmers collectively hire the services of agronomists.

Another complementary proposal was to encourage effective mill traceability schemes. This means performing analyses when the olives are delivered to the mill, which entails logistic and management problems.

Participants concurred that the industry must keep a watch on *fraud* because it distorts price formation, leads to a loss of reliability of standards and causes tangible damage to the numerous quality oils on the Spanish market.

The first threat is the addition of extraneous oils to olive oil, especially to refined oil. Although sufficient research has been carried out to control this problem to a large extent, fraud inspection is the crux of the matter and is very expensive. On the one hand, there are more than 20 types of analytical indicators for checking if product is solely olive oil. Research is also underway to test new techniques based on molecular biology which would appear to improve testing through the use of molecular markers[11]. Nevertheless, it is considered essential to concentrate on developing quick, simple methods for detecting the addition of extraneous oils.

The authenticity of extra virgin olive oil is the second major issue connected with the potential for fraud. According to the panel members, this is more a question of certification and transfer than of basic research. For instance, it should not be left to producers to decide whether an oil is "extra virgin"; this should be certified by an independent agency. The fact of the matter is that there are virgin olive oils labelled as extra virgin that do not display the sensory quality required for classification in this category:

"I think there should be a system in place that offers external guarantees and which is industry-backed and funded".

Figure 6 reports the results of the participatory strategic workshop on food safety and olive oil fraud.

[11] When referring to research in Spain on food safety, fraud detection and the chemical components of olive oil and its by-products, a special mention should be given to *Grasas y Aceites. International Journal of Fats and Oils,* published by the Fats & Oils Institute (CSIC) where a large number of researchers are working on these subjects.

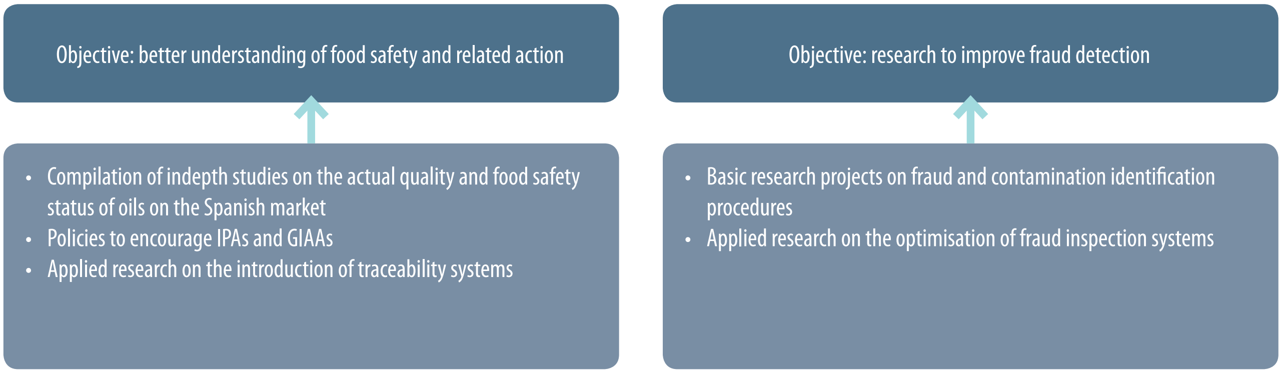

Figure 6: Strategic recommendations on food safety and oilve oil fraud

Mill innovation, olive oil quality and health

From the innovation angle, ***oil quality*** has improved greatly in Spain in the last two decades, driven by the advances in olive oil processing and packing technologies as well as by good practices in olive growing, harvesting, processing and oil storage[12]. Nevertheless, the experts mentioned insufficient professionalisation and training of master millers and mill yard managers as the biggest failings in the sector. Hence, continuing efforts are needed in vocational and business training:

"Master millers and mill yard managers tend not to have sufficient sensory quality training. Mill management and consumers are not sufficiently trained."

Research in Spain has made considerable progress in the obtention of quality oil although the panel agreed that the effort expended on quality improvement has not gone hand in hand with a suitable quality promotion strategy. This is a truly critical point in the Spanish olive oil industry. It is necessary to reorient business innovation policy, which must boost marketing strategies aimed at achieving market recognition of quality[13].

Research programmes on ***olive oil and health*** have lately been given an impetus in Spain. Results are currently being obtained on the antioxidants in virgin olive oil, which have anti-inflammatory and anti-carcinogenic properties, as well as on postprandial mechanisms[14]. In addition, the experts underscored the future importance of research into the production of foods in which saturated fats are replaced by virgin olive oil.

However, so far research results have been transferred to the industry and consumers to only a very limited extent. The experts pointed out that the transfer of research findings to consumers has to be viewed in a broader context of relaying a multi-attribute concept of olive oil where "health" and other attributes such as "origin" or "sensory quality" are grouped as a whole in consumer minds. Consequently, it is urgent to boost consumer information and education to make consumers more knowledgeable about the taste and health properties of olive oil, for instance through programmes for school children or in the media. Emphasis was placed on the need to undertake a broad transfer programme involving research centres and hospitals, producers and packers, consumer associations, the Spanish Olive Oil Interbranch Association and the Administration. Some research networks of this type are already in place, for example the CEAS network (Spanish acronym for the Olive Oil and Health Research Network) which brings together health professionals and researchers in olive oil technology and others.

The outcomes of the strategic participation workshop on olive oil mill innovation, olive oil quality and health are shown in Figure 7.

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[12] Some of the literature dealing with aspects of olive oil processing or olive oil quality include Aparicio and Harwood (2003), Civantos (2008) and Uceda *et al.* (2008).

[13] See section on consumer behaviour and marketing strategies.

[14] Papers reporting the scientific results of research on olive oil and health include López-Miranda *et al.* (2010), Quiles *et al.* (2006) and Sánchez-Quesada *et al.* (2013).

Objective: research on oil quality and mill innovation

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- Joint research projects by RDI centres and companies on oil quality and mill innovation
- Projects on the energy sustainability of olive oil mills
- Innovation and development of mill automation technologies: pilot plants

Objective: transfer and dissemination of knowledge on oil quality and mill innovation

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- Transfer of quality findings from RDI centres to companies within the scope of the Spanish Olive Oil Interbranch Organisation

Objective: applied research and RDI collaborative networks on olive oil and health

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- Promotion of empirical research on hospitals and/or patients in relation to diet, virgin olive oil and health
- Promotion of collaborative networks of RDI centres, hospitals and the Spanish Olive Oil Interbranch Organisation on olive oil and health

Objective: dissemination of knowledge on olive oil and health

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- Consumer education and promotion of health-promoting properties of olive oil
- Specific action to inform consumers on the valuable health-promoting compounds in olive oil

Figure 7: Strategic recommendations on mill innovation, health and olive oil quality

New products derived from olive growing and olive oil

Present-day research has made great progress in identifying the positive effect of olive oil-based *cosmetics* on the skin. However, the production sector is generally unaware of these findings and there is hardly any action to transfer the pertinent technology to the olive oil industry. Prospects look bright for the demand for olive oil cosmetics because consumers are significantly more willing to pay for cosmetics than for oil. One point to bear in mind is that the commercial margins of olive oil-based cosmetics are very high (almost 100%) and much greater than those of olive oil. Cosmetics manufacturing could be a source of considerable additional income and could help to make production less seasonal:

"When you try to sell extra virgin olive oil, you do a lot of talking but the person opposite doesn't listen for long. You realise they're just not interested... but if you start talking about cosmetics, you get their attention and all sorts of possibilities open up."

In the case of *olive leaves*, one key aspect of their utilisation is to extract their valuable minor compounds for potential application in the food and pharmaceutical industries. Here there is a problem of basic research because little is known about this subject. Olive leaf applications could be a future source of extra income in marginal olive farming districts.

Other avenues of basic research waiting to be explored are the potential reuse of the antioxidants in olive rinse water and the promising obtention of valuable minor compounds from oils and olive pomace.

Figure 8 shows the results of the strategic participation workshop on the new products derived from olive oil.

Objective: basic research

↑

- Research on valuable compounds in olive oil and how they relate to quality, value generation and health
- Research on potential uses of the compounds in by-products and residue: olive pomace, olive stones, pruning debris, olive leaves and olive rinse water

Objective: cooperation between RDI centres and companies

↑

- Creation of RDI centre/industry projects on new product development
- Transfer of results and promotion of the use of olive oil as a substitute for the fatty acids in various foods

Figure 8: Strategic recommendations on new products derived from olive growing and olive oil

Marketing, organisation, heritage and territory in the olive oil sector

Consumer behaviour and marketing strategies[15]

The experts first stated that research on olive oil supply is more consolidated than that on demand because olive oil economies are currently more oriented towards a supply model than a demand model. Although theoretical research on food demand models and techniques is quite far forward on an international scale, the experts agreed that the biggest research gaps are in concrete knowledge about the *behaviour of olive oil consumers* in the different segments and markets, especially international ones.

Lack of consumer knowledgeability about product characteristics is the chief obstacle to *olive oil consumption*. Although this lack is logically more pronounced on international markets, it is also quite evident among Spanish consumers. From a marketing standpoint, the solution lies in communication, promotion and advertising policies as well as in sensory education programmes for consumers in which tutored tastings are a very important tool[16]. The experts therefore suggested driving applied research to analysis the psycho-social and economic factors that define behaviour in the different olive oil consumption segments:

"I keep on wondering why Spanish consumers, who are used to eating olive oil, do not distinguish between extra virgin and normal olive oil. I think this would be a question for sociological and perhaps even psycho-social research and would be well worth investigating."

There was also a consensus among the experts that demand for new olive oil-based products – for instance meat products where saturated fatty acids have been replaced by oleic acid from extra virgin olive oil and canned products and processed baked goods in which olive oil is used instead of other fats – will gain increasing importance in the future.

Olive oil market penetration is an important area of research on *marketing strategies,* which have to be differentiated according to the target market channel and segment as well as the type of business (large cooperative, small private mill focused on quality differentiation, etc.).

When addressing the question of the penetration of packed olive oil on the *domestic market*, the experts agreed that the main stumbling blocks are the major business concentration in the large-scale distribution sector and the fact that such businesses use oil as a loss leader. As a result, agricultural or processing margins are very low. The experts also said that the domestic olive oil market in Spain is not mature, thus making it the prime target for increasing olive oil consumption in the near future:

"I think Spain is the best market for increasing consumption, at least of extra virgin olive oil. Is there also room for increasing olive oil consumption in general? The answer is yes, chiefly in restaurant, hotel and catering channels and even in institutional food service because households have a higher market share which is harder to expand".

When it comes to packed oil penetration on *international markets*, the Spanish olive oil sector has still only a short albeit intense track record because for many decades the market basically focused on home consumption. More recently, the climate has been conducive to increasing olive oil demand, which has absorbed higher levels of production:

"In foreign markets, olive oils are positioned as the healthiest oils…Demand is growing, even without promotion and communication strategies."

Promotion and communication strategies should be adapted to the peculiarities of demand in the countries of destination. For this to happen, it is crucial to investigate which attributes are most highly rated in the different domestic markets because consumer behaviour varies widely from country to country. Applied research should also investigate how olive oils can be combined with non-Mediterranean cuisines and what communication strategies help to increase product penetration:

"Olive oils are positioned in usage segments entailing little cooking time, such as salads. This limits the opportunities for demand growth …. I would carry out promotion linked to each national or local cuisine."

Labelling was a topic that generated differing but complementary opinions during discussion. One was that if consumers do not know about extra virgin olive oil, putting too many details on the product label will only flood them with information and make the message less effective. Another was that the label is the only quick, cost-free

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[15] Parras Rosa and Muñoz Guarasa (2012) report recent research on consumption, business strategies, marketing and cooperatives in the Spanish olive oil sector while the paper by Rodríguez-Cohard and Parras Rosa (2012) gives an overview of olive oil marketing channels in Spain.

[16] Alba Mendoza (2008), Jiménez Herrera and Carpio Dueñas (2008) and Uceda *et al.* (2010) have written three helpful guides to olive oil tasting to familiarise consumers and economic operators with sensory analysis.

source of information for consumers; hence, because they do not have a lot of time, labelling information has to be kept short and sweet and understandable in 15 seconds.

Figure 9 summarises the results of the strategic participation workshop on consumer behaviour and marketing strategies.

Objective: better understanding of olive oil consumer behaviour

- Research on consumer behaviour in the chief importer countries and domestic consumption segments
- Research on consumer behaviour vis-à-vis olive oil categories and by oil attributes
- Market research on what would make consumers willing to modify their oil consumption
- Study on the potential uses of olive oil in the gastronomy of target countries or regions
- Improvement of the Ministry of Agriculture Olive Oil Consumption Panel
- Analysis of potential markets for organic oils

Objective: better understanding of the demand for new products and by-products

- Studies on the demand for food products in which olive oil could potentially be used: technical and economic feasibility of uses
- Studies on the non-food diversification of oil use
- Analysis of the profitability and/or logistics of olive biomass utilisation

Objective: better understanding and dissemination of olive oil attributes and culture

- Study on the attributes characterising the link between oil production and territory
- Study on the inclusion of positive attributes in olive oil labelling
- Design of measures for effective oil quality communications strategies on international markets
- Campaign to disseminate olive oil sensory analysis to business operators and consumers
- Promotion of nutritional and sensory benefits of olive oil

Figure 9: Strategic recommendations on consumer behaviour and marketing strategies

Business organisation of the olive oil mill industry and cooperatives

While the objective of olive oil mills is to sell a larger proportion of packed, branded olive oil, the bulk market cannot be overlooked because it is still the major destination for the olive oil sold by producers in Spain. The main problem facing the olive oil industry is that it is heavily fragmented (1700 mills) compared with the packing industry and distribution sector which are distinctly oligopolistic. This means that mills have little negotiating power and leads to a structural decline in the prices paid to producers. Besides considering it necessary for mills to form business teams, the experts thought it essential to conduct research to establish criteria for making mills more professional, especially as regards their commercial functions because many cooperatives have a shortage of proper managerial and commercial staff:

"Another serious problem is that mills are no longer the only ones to sell oil; farmers now tell mills to sell their oil for them. As a result, there are more sellers and sales timing is not rationalised. Oil is sold at any time for numerous reasons – a daughter's wedding, a village fiesta, … – but never according to professional sales criteria."

The experts discussed the question of the most appropriate organisations for combining the production and commercial aspects of the sector. One proposal was to concentrate *cooperatives* into larger first-tier units (first-tier cooperatives are cooperatives whose members are natural or legal persons) that are more capable of making their employees more professional. For instance, there are still many towns and villages where there are several cooperatives. Grouping together at municipal level would lower production costs and aggregate supply.

According to the experts, another factor that heavily restricts the business capability of cooperatives is the principle of "one man, one vote" because small, part-time farmers cannot play the same role as professional farmers who earn their living from their holding. Cooperatives are often affected by social dynamics that are not explained merely by a drive for profits (Ruiz, 2006). The experts therefore proposed carrying out research on the sociological, economic and anthropological mechanisms that influence the internal dynamics of cooperatives and transferring the results.

Second-tier cooperatives (cooperatives made up of two or more cooperatives) are a tool for joint marketing of first-tier cooperatives. However, there was not a consensus amongst the experts on the role they should play. While some thought it was positive to encourage their creation others believed it was important to begin by promoting first-tier cooperatives that are sufficiently large and professional.

Figure 10 outlines the outcome of the strategic participation workshop on cooperatives and the business organisation of the olive oil mill industry.

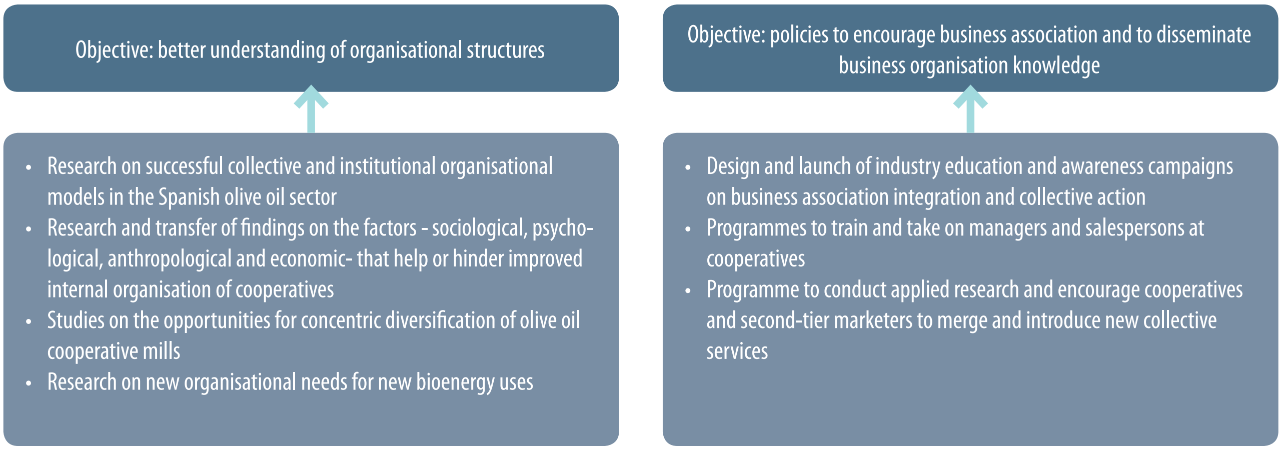

Figure 10: Strategic recommendations on the business organisation of the olive oil mill industry and cooperatives

Quality certification and designations of origin

The experts pointed out that product differentiation is not made by producers but exists in the minds of consumers. In concrete, *differential quality certification* strategies such as protected designations of origin (PDOs), organic olive growing or integrated production have to become more demand-oriented; in Spain, this has not been the case as often as might have been wished. The general debate on oil differentiation revealed that it had possibly become too segmented as regards consumer ability to recognise and appreciate the differential attributes of an oil:

"Is organic a differential element? Yes, without a doubt. Are PDOs a differential element? Yes. Is integrated production a differential element? Yes … sometimes we think of differential attributes as if they were for ourselves (experts and connoisseurs) .. but we make up only a very minor part of the market. The success of a differentiation strategy is basically dependent on demand, not supply."

Firstly, it was proposed researching into the environmental differentiation attributes of olive oil and the market niches and segments that seek these attributes: this is the potential case of the organic oil and integrated production segments[17], although the latter is barely known to consumers.

Secondly, consumers consider *designation of origin* labels to offer guarantees of sensory quality although this does not necessarily imply that the DO regulations feature stricter requirements for DO oils than for extra virgin product, which is the case, however, of some protected designations of origin (PDOs). Olive oil PDOs have spread rapidly in Spain in recent years, especially since 2000 and by 2014, there were 28 recognised PDOs[18]. The discussion analysed the factors limiting the efficiency of the current Spanish model of olive oil PDOs. Many designations are not becoming a tool for integration and commercial promotion; as a result, olive farmers who expect more immediate benefits may consider PDO membership to be an extra cost. Although consumers have a positive perception of "origin", PDO oils are not managing to become well known:

"In various surveys on olive oil consumption, "origin" has systematically come up 3 to 4 points ahead of PDO while "PDO" has been in the tail group of factors."

When considering the achievements of PDOs, the experts highlighted that they have created producer and consumer awareness of oil quality, which has brought indirect beneficial effects for the entire sector. They also acknowledged that one of the most positive consequences

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[17] See section on organic olive growing, integrated production and biodiversity.

[18] Research on interbranch and institutional activity in regard to olive oil PDOs in Spain includes papers by Coq *et al.* (2014), Sanz-Cañada (2009) and Sanz-Cañada and Macías-Vázquez (2005).

of institutional PDO activity has been to encourage local interbranch olive oil organisations. This is particularly effective in hitherto disadvantaged areas without any unifying institutions for local olive oil development[19]. It was proposed encouraging research into the socio-economic and cultural factors that promote the unification of the local producing and commercial sector, on the basis of successful experiences. It was also suggested investigating what attributes of PDO oils ought to be used in marketing strategies and how to incorporate them into territorial promotion as a whole.

The strategic participation workshop on quality certification and designations of origin gave the results shown in Figure 11, together with those now outlined in the next section.

Objective: research on multi-functionality and local olive oil development institutions

- Study of the repercussions of orchard abandonment in marginal olive growing areas
- Applied research on the design of machinery suitable for use in steep orchards; promotion of cooperation among researchers, machinery manufacturers and users
- Analysis of the economic profitability of marginal olive farms and quantification of its social and environmental functions
- Basic and applied research on the environmental appraisal of olive irrigation
- Design of public policies on the analysis and appraisal of environmental and rural development externalities
- Research on the dynamics of rural and institutional development: designations of origin and second-tier cooperatives

Objective: research and better understanding of olive landscapes and heritage

- Inventory of cultural and natural olive growing and olive oil heritage: architecture, culture, landscape and ecosystems
- Research to identify people's preferences in terms of olive landscapes
- Basic and applied research on the effects of the spread of organic agriculture in highland olive landscapes and natural parks

Objective: design of olive oil tourism strategies

- Studies on olive oil tourism potential in highland olive growing areas and unique orchard agro-systems
- Design of olive oil tourism value-addition strategies in partnership with local stakeholders

Figure 11: Strategic recommendations on quality certification, designations of origin, multi-functionality and olive landscapes

Multi-functionality and olive landscapes

Analysis of the *multi-functionality* of olive growing and olive oil production figured prominently in the panel discussion and may have considerable implications for public policies[19]. The experts agreed that in their capacity as the producers of public goods, local production systems where low-yield, mountain olive growing is practised are the areas in greatest need of public policies. Such marginal olive orchards are not able to convert to irrigated cultivation; moreover, their profitability is seriously hampered by the physical environment. According to the experts, almost one-third of Spain's olive orchards (800 000 ha) fall into this category.

As a producer of public goods, mountain olive growing fulfils purposes demanded by society as regards the landscape, environment, biodiversity, land occupation, curb on rural depopulation, income supplementation, etc. Consequently, if it complies with environmental and sustainable development requirements, it has the social legitimacy to be funded under public policies. In such circumstances, it is hard for marginal olive grow-

[19] When discussing regional and environmental policies, the experts recommended annually updating the study on Olive Growing in Andalusia (Junta de Andalucía, 2003), as well as making it nationwide in scope. This study quantified a series of variables at territorial level by type of cultivation system: characteristics of the physical environment, agricultural structures, levels of productivity, etc. It provides very significant information for policy making.

ing to compete price-wise with the new intensive and superintensive form of olive cultivation that is expanding worldwide.

These problem areas prompted applied research to evaluate the extent to which olive growing in Spain is physically marginal. According to Guzmán Álvarez (2004) one-fifth of the olive orchards in Andalusia could be considered marginal (200 000 ha) on the basis of physical marginality criteria relating to land slope and soil type. However, the absence of an appraisal of the physical and economic marginality of all of Spain's olive orchards is currently a shortcoming for the implementation of multi-functional policies.

In this respect, the experts mentioned the importance of researching into the profitability thresholds at which olive farms may be abandoned in different olive growing districts according to the features of the physical environment, productive yield, agricultural structures, extent of public policy support, etc. Another important research topic would be to design environmental and economic alternatives for olive orchards with the greatest likelihood of being abandoned.

It was also considered advisable to set in motion an RDI programme to appraise and classify the roles of olive growing when viewed as a public good[20], as well as to determine the type of requirements to lay down for low-yield olive orchards:

"What arguments should be taken into account when considering what to do with marginal olive orchards? On the one hand, there are emotional and aesthetic arguments linked to the landscape; on the other, there are arguments linked to society and people, and lastly the idea that these olive orchards are an agro-environmental public good. So, what public goods do these orchards offer? This should be the focus of research work."

Nevertheless, there was some dissent about the advisability of using public money to reward the reduction of negative environmental externalities in more marginal olive orchards. Some experts proposed allowing certain marginal olive orchards to turn into dehesa grassland:

"Major olive orchard conversion is necessary to modernise orchards in many places. But there are also many areas where olive growing does not make sense … the best thing that could happen in such cases would be to allow the orchards to revert to dehesa grassland which they should never have stopped being."

Lastly, some of the specialists mooted the possibility of applying public agro-environmental policies not just to hilly orchards but also to medium-yielding, rainfed orchards which are the most frequent type found in Spain (more than 1 200 000 ha, according to the experts).

Olive tourism and local differential quality strategies can achieve joint synergies in promoting intangible territorial assets and complement each other in generating income. The experts also pointed to the loss of important architectural heritage, especially typical farmhouses which were models of rural architecture and which could be more closely involved in the expansion of olive tourism.

Closing remarks

The working basis of the in-person expert panels was to gradually reach a degree of consensus in interactive dialogue and the formulation of strategic recommendations.

From a cross-sectional standpoint, a consensus first emerged on the general dearth of action in transferring innovations and knowledge from the national RDI system to businesses and farmers. Generally speaking, in many of the theme areas, transferring innovations and knowledge is more urgent than conducting research in the strict sense of the word. This finding is quite patent in the case of RDI to correct environmental externalities in olive growing and olive oil production, as well as regarding consumer behaviour, quality practices, innovations in processing methods or other aspects. The national system needs to find a solution to this bottleneck in future development, especially since nowadays Spanish olive oil companies are not inclined to be demand-oriented or to take on board innovations.

A second widespread opinion is that it is necessary to take interdisciplinary and transdisciplinary approaches to RDI involving researchers with different specialities. The issues the national system has to grapple with are becoming increasingly complex, as is only too evident in spheres such as quality, food safety, sustainability or multi-functionality. In actual fact, action so far has been disciplinary in approach. Upon analysis, it emerged that the disciplinary and longitudinal approach taken in this article needed to be supplemented by interdisciplinary analysis. For this reason, the sequence of social research methods led to a third phase of the research

[20] Arriaza and Nekhay (2010), Carmona-Torres *et al.* (2014), Gómez-Limón (2010), Parra-López *et al.* (2004) and Pérez and Pérez *et al.* (2013) have written recent research papers appraising the functions of local olive oil systems as public goods.

project[21] based on the cross-sectional, transdisciplinary relationship between technical knowledge (agricultural, processing, ecological, etc.) and knowledge in the field of the social sciences[22].

Agreement also emerged on the urgent need to adopt a territorial approach to resolving environmental and rural development problems in the olive and olive oil sector. Applied research and transfer programmes need to take into account the heterogeneity of the environment and management practices and the large degree of diversity in the socio-economic, cultural and institutional environment of the geography of olive growing in Spain.

In short, a process of interactive dialogue between researchers and experts from a wide range of subject areas aimed at identifying important issues in the olive and olive oil sector and offering sustainability-oriented knowledge highlighted the importance of transdisciplinary research in the search for solutions to complex problems. The practices employed and underlying principles fall under what Lang *et al*. (2012) term *sustainable science*. The outcome of this process was a consensus on the need to drive RDI policies and programmes for the Spanish olive oil sector to ensure that Spain's world leadership in olive oil production also goes coupled with leadership not only in research but also in innovation and transfer. Furthermore, the structural changes in the olive oil chain and consumption and the new direction of the 2014/20 Common Agricultural Policy call for special efforts to design programmes that overcome the current excessive fragmentation of research teams and disciplines. Doing so would help to find answers to complex problems, although its success will depend on involving the scientific community, industry stakeholders and territorial development institutions in the decision-making process.

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[21] See Figure 1.

[22] The methodology in the third phase entailed carrying out two Delphi analyses on a large number of experts (85 in all) in two major cross-sectional and interdisciplinary theme areas: i) value chain, quality, food safety and consumption (food chain approach) and; ii) sustainability, territory and rural development (territorial and environmental approaches).

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