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Original Article

Organic Agriculture and Innovative Crops under Mediterranean Conditions

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Abstract

Climate change is the greatest environmental threat facing humanity worldwide. Areas of South-East Europe and Mediterranean basin are expected to be among the most vulnerable countries to climate change. As a result of climate change, new species and crops have been introduced and may be introduced in the coming years. In addition, *FAO* considers that Organic Agriculture is an effective mitigation strategy to climate change and can build robust soils that adapt better to weather extremes associated with climate change. This review provides an overview of the growth performance of new innovative crops, including chia, camelina, quinoa, teff and nigella and retrovative crops such as flax and emmer wheat, based on experimental investigations conducted under Mediterranean conditions and organic cropping system. Several studies, performed under organic system, have proved that innovative crops can also be grown for alternative uses. Quinoa and chia could be successfully used in animal feed. Moreover, quinoa could be exploited as a medicinal plant due to saponins extracted from seed coats. Nigella and camelina seeds contain oils which can have several uses in pharmaceutical and food industries. Flax seed oil is rich in omega-3 fatty acids and can be accepted in the diets designed for specific health benefits. According to the literature, it is observed that innovative crops cultivated under organic system present better quality and similar yields as with those cultivated under conventional system, and in some cases, even higher. Taking all these into account, organic agriculture could also be characterized as innovative and not only as traditional.

Keywords: climate change, innovative crops, Mediterranean conditions, Organic Agriculture, retrovative crops

Introduction

Climate change consists the greatest environmental threat facing humanity worldwide. It is a natural process but, in the light of recent surveys, this dramatic change is mainly due to the increase of various greenhouse gases (GHG) emissions as a result of anthropogenic reasons. Agriculture is actually affected by climate change but also plays a part in the rise of problem. Agriculture is the third largest contributor of greenhouse gas emissions, mainly including methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). The Intergovernmental Panel on Climate Change (IPCC) states that greenhouse gas (GHG) emissions from the agricultural sector suggest 10-12% of the total anthropogenic annual emissions of CO_2-equivalents (IPCC, 2007). In addition, agriculture contributes about half of global emissions of methane and nitrous oxide (World Bank, 2008). It has to be noted that emissions due to the production of agricultural inputs such as synthetic fertilizers and pesticides, fossil fuels used in the production of agrochemicals and agricultural machinery and irrigation are not included and should also be taken into account (El-Hage Scialabba and Müller-Lindenlauf, 2010). Regarding the high contribution of agriculture to greenhouse gas emissions, the choice of alternative agricultural practices is the only solution to cope with problem of climate change.

Agriculture is highly depended on climate conditions. Changing environmental conditions such as rising temperatures, changes in precipitation patterns and an increase of extreme weather phenomena have the potential to affect productivity in agriculture, making it even more prone to failure (El-Hage and Müller-Lindenlauf, 2010).

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The Mediterranean region is characterized by an extremely variable climate with warm dry summers and cool rainy winters (winter rainfall is more than three times summer rainfall), being a transition between dry tropical and temperate climates (Ceccarelli *et al.*, 2007). Mean annual temperatures range from 9 to 20 °C and mean annual rainfalls vary from 200 to 2000 mm, depending on altitude (Carrubba and Scalenghe, 2012). The future climate change scenarios prognosticate drier and warmer conditions in the Mediterranean region, including southern Europe, as a result of global warming (IPCC, 2007). A mean temperature rise is predicted with values ranging from 2-4 °C (Georgakopoulos *et al.*, 2016). Moreover, specific forecasting models show that rainfall during the winter will be increased in central and eastern Spain and the northern part of Italy, while in southern Mediterranean countries the rainfall will be decreased by 10-15% until the year 2050 (Ragab and Prudhomme, 2002).

The influence of climate change is expected to lead to large reductions in Mediterranean crop productivity (Maracchi *et al.*, 2005) with increased water demand hastened maturation and reduced yields for spring crops and geographically variable effects for autumn crops (Rötter and van de Geijn, 1999; Giannakopoulos *et al.*, 2011). Areas of South-East Europe and Mediterranean basin are expected to be among the most vulnerable countries to climate change. As a result of climate change, new species and crops have been introduced and may be introduced in the coming years (Georgakopoulos *et al.*, 2016).

Organic Agriculture is not only able to adapt to the effects of climate change in agriculture-influenced ecosystems but also has the potential to reduce emissions of agricultural greenhouse gases (GHG) (Khanal, 2009). Mitigation is an effort to reduce greenhouse gases that are responsible for climatic change and global warming. The Food and Agriculture Organization of the United Nations (FAO) considers that Organic Agriculture is an effective mitigation strategy to climate change and can build robust soils that adapt better to weather extremes associated with climate change (Niggli *et al.*, 2009). Organic Agriculture as a mitigation strategy addresses both reduction of greenhouse gas emissions and soil carbon sequestration. Reduction of greenhouse gas emissions is achieved through lower N_2O emissions with lower nitrogen input and less CO_2 emissions better soil structure, more plant cover and lower farming system inputs (Müller, 2009). Soil carbon sequestration is increased through agricultural management practices such as the application of organic manures and the use of intercrops and green manures that enhance soil organic matter contents and improve soil structure (Niggli *et al.*, 2007). Therefore, Organic Agriculture helps to increase resilience of farming systems by using recycling techniques and low external input and high output strategies (Kotschi and Müller-Sämann, 2004; Niggli *et al.*, 2007).

This research article attempts to provide an overview of the growth performance of new innovative crops, including chia, camelina, quinoa, teff and nigella and retrovative (from the words retro and innovation) crops such as flax and emmer wheat, based on the first results of experimental studies conducted under Mediterranean conditions and organic cropping system.

Innovative Crops: General Information and First Results of their Cultivation

Quinoa

Quinoa (*Chenopodium quinoa* Willd.) has a significant potential for increased production as a new cultivated crop in the Mediterranean region and in other areas of the world including North America, Europe and Asia (Jacobsen, 2003). It is characterized as one of the crops that could provide food security, especially in the future climate scenario of increasing salinization and aridity (Jacobsen, 2003; Ruiz *et al.*, 2014). Quinoa, a member of Chenopodiaceae family, is a pseudocereal crop well adapted to grow under unfavourable soil and climatic conditions (Garcia *et al.*, 2003) and has been traditionally cultivated for thousands of years in the Andean highlands of Bolivia, Peru, and Ecuador for its nutritious grains and leaves (Pearsall, 1992). Archaeological findings in northern Chile have shown that quinoa is cultivated there for more than 7000 years (Jancurová *et al.*, 2009). Over the last thirty years, quinoa seed has become an extremely popular food product, especially in Europe and North America (Jellen *et al.*, 2015), because of its exceptional nutritional value (Repo-Carrasco *et al.*, 2003). Quinoa grain is gluten-free and therefore can be eaten by people who have celiac disease (Pulvento *et al.*, 2010). It has a high protein content (14-20%) containing essential amino acids such as lysine, methionine and threonine which are limiting in cereals (Bhargava *et al.*, 2007). Moreover, quinoa is rich in vitamins C, E and B complex, minerals, isoflavones and lipids (Koziol, 1992). The saponins, constituted up to 6% of seed coat, can be exploited for industrial and biomedical purposes (Vega-Gálvez *et al.*, 2010). The aerial biomass of quinoa has been used as green fodder for animals such as cattle, pigs and poultry (Bhargava *et al.*, 2006). Therefore, this species is considered as a multi-purpose agricultural crop with potential uses for both human and animal consumption and nutrition. The Food and Agriculture Organization of the United Nations (FAO) has declared the year 2013 as the international year of quinoa (FAO, 2012).

Data obtained from several studies conducted in areas of Mediterranean basin demonstrate the beneficial effects of organic farming in quinoa crop (table 1). Bilalis *et al.* (2012) conducted a two-year experiment in western Greece to investigate the influence of soil tillage [conventional tillage (CT) and minimum tillage (MT)] and organic fertilization [fertilization treatments: control, cow manure (2000 kg ha^{-1}) and seaweed compost (250 kg ha^{-1})] on growth, yield and quality of quinoa and found that the highest saponin yield (7.70-12.05 kg ha^{-1}) was observed in soils subjected to minimum soil tillage. Also, there were significant differences between the fertilization treatments with the highest values of seed yield (2485-2643 kg ha^{-1}) and saponin content (0.42-0.45%) observed in manure and compost treatments. Papastylianou *et al.* (2014) studied the response of quinoa and amaranth to different fertilization regimes [(control, inorganic fertilization (fertilizer 26-0-0 with 100 kg N ha^{-1}), compost (2000 kg ha^{-1}) and cow manure (2000 kg ha^{-1})] and found that fertilization with compost showed higher values in yield (8430 kg ha^{-1}) and quality traits (18.8% total ash, 2.87% crude fat and 14.7% crude protein) of quinoa biomass. They suggested that quinoa could be used as an alternative feed crop for substitution of spring legume species in Mediterranean semi-arid areas.

Chia

Chia (*Salvia hispanica* L.) is an annual plant of the Lamiaceae family and originated from southern Mexico and northern Guatemala (Ayerza and Coates, 2005). In pre-Columbian period, chia seeds were one of the four main components in the diet of Mesoamerican civilizations (Bochicchio *et al*., 2015). Currently, it has been rediscovered (Ayerza and Coates, 2009) and received remarkable attention due to its exceptional nutritional value (Borneo *et al*., 2010; Ixtaina *et al*., 2011). Seeds are great sources of polyunsaturated fatty acids, antioxidants, vitamins and minerals (Ayerza and Coates, 2009). The oil content of chia seeds ranges from 25 to 40%, consisting 60% ω-3 alpha-linolenic acid and 20% ω-6 linoleic acid (Mohd Ali *et al*., 2012). Both of these essential fatty acids are required by the human body for its health and they cannot be artificially synthesized (Pizarro *et al*., 2013). Several studies reported that chia consists one of the richest natural sources of ω-3 fats and hence chia seeds were successfully used to increase the ω-3 fatty acid content of animal products such as eggs, poultry and pork meat (Ayerza, 2011). In Europe, the use of chia for human consumption has been approved by the European Parliament and the European Council according to the directive 2009/827/EC (European Commission, 2009).

Bilalis *et al*. (2016) established a field experiment to determine the effect of plant densities (row spacing: 60 and 40 cm) and organic fertilization [fertilization treatments: control, organic fertilizer (fertilizer 6-8-10 at a rate of 1000 kg ha^{-1}) and sheep manure (1800 kg ha^{-1})] on growth and fodder quality of quinoa crop under Mediterranean conditions. According to the results, there was a positive effect of increasing row spacing on biomass production (5587 and 14190 kg ha^{-1} for 40 and 60 cm, respectively). Fodder quality parameters were actually affected by organic fertilization. The highest crude protein (13.25%) and acid detergent fiber (ADF) content (42.45%) were observed in organic fertilizer treatment, while, the highest neutral detergent fiber (NDF) (49.57%) content was recorded under manure treatment. According to the authors, these high values can meet the requirements of lactating animals. Moreover, they emphasized that chia biomass is produced during the summer which is very important for the nutrition of ruminants since there is a lack of natural vegetation during this period.

Nigella

Nigella (*Nigella sativa* L.) is an annual medicinal plant of the Ranunculaceae family and is native to areas of southern Europe, North Africa, South and West Asia (Tuncturk *et al*., 2005). It is cultivated from the countries of the southern and eastern areas of the Mediterranean basin to Iran, Pakistan and India for seed yield and oil production (Gharby *et al*., 2015). Its seeds, the only part of the plant harvested and exploited, have been subjected to a series of pharmacological studies over the last three decades. The studies have shown that nigella seed oil and extracts have diuretic, antihypertensive, antidiabetic, anticancer, anthelmintic, analgesic, antimicrobial, anti-inflammatory, spasmolytic, hepatoprotective, gastroprotective, nephron-protective, antihypertensive and antioxidant effects (Riaz *et al*., 1996; Ahmad *et al*., 2013). The seeds are rich in unsaturated essential fatty acids, among which linoleic, oleic and palmitic acids are the most abundant (Kizil *et al*., 2008). In addition, the nigella seeds are also a source of minerals, including Fe, Na, Cu, Zn, P, Ca and vitamins such as ascorbic acid, thiamin, niacin, pyridoxine, and folic acid (Takruri and Dameh, 1998). Nigella seeds contain 30-35% oil and 0.5-1.5% essential oil which have several uses for pharmaceutical and food industries (Üstun *et al*., 1990; Ashraf *et al*., 2006). Thymoquinone is the major active compound in the crude extract of nigella oil and is characterized for antioxidant and anti-inflammatory effects in models of *in vitro* and *in vivo* studies as well as asthma, diabetes, encephalomyelitis, neurodegeneration, and carcinogenesis (Woo *et al*., 2012).

Fig. 1. Established nigella crop at flowering stage (June, 2016) in the organic experimental field of the Agricultural University of Athens (Roussis *et al*., 2017)

During the spring and summer of year 2016, Roussis *et al*. (2017) set up an experiment at Agricultural University of Athens to investigate the effects of different seed rates (50 and 60 kg ha^{-1}) and fertilization [fertilization regimes: control, compost (2000 kg/ha), sheep manure (2750 kg/ha), inorganic fertilizer (15-15-15+5 S, 400 kg/ha)] on growth, yield and yield components of nigella crop (Fig. 1). They found that the different seed rates significantly affected the plant height with the highest values (18.2-22.7 cm) recorded with 60 kg ha^{-1}. Moreover, they observed that seed yield and biological yield were significantly affected, maximum parameters (911-1066 kg ha^{-1} and 3864-4063 kg ha^{-1} for seed yield and biological yield, respectively) were recorded with inorganic fertilization followed by compost (828-881 kg ha^{-1} and 3239-3455 kg ha^{-1} for seed yield and biological yield, respectively). They eventually demonstrated that there is a clear need for further studies on performance of nigella under Mediterranean conditions.

Teff

Teff (*Eragrostis tef* (Zucc.) Trotter), a member of the Poaceae family, originated in Ethiopia around 4000-1000 BC and is mainly grown for its grain mainly used in human consumption (Stallknecht *et al*., 1993; Tesfahunegn, 2014). It is a warm season C_4 annual plant (Bedane *et al*., 2015) and is intermediate between tropical and temperate grass (Stallknecht *et al*., 1993). Teff has the potential to be one of those crops with beneficial health effects as it contains very low gluten, making it an extremely important component for the diet of people with either gluten intolerance or celiac disease (Roseberg *et al*., 2006). Teff makes excellent quality straw and has various uses mainly as fodder for cattle, and secondarily as bedding material, mulch and domestic fuel source (Assefa *et al*., 2001). In addition, teff is also gaining the interest of the people of Western world and serious efforts are being made to expand its cultivation in Europe and America (Belay *et al*., 2009).

Chroni (2016) established a field experiment in Greece during the summer of 2015 to investigate the effect of different plant densities (row spacing treatments: 20, 40 and 60 cm) and fertilization (control, organic fertilizer (Bokashi) at a rate of 4200 kg ha^{-1} and inorganic fertilizer (34.5-0-0) at a rate of 60 kg N ha^{-1}) on agronomic characteristics and yield of teff crop under Mediterranean conditions (Fig. 2). According to the results of this study, plant densities had no significant effect in teff measurements. On the contrary, fertilization had significant effect on number of grains per panicle but it did not affect the seed yield. The highest value (approx. 840 seeds per panicle) was recorded in organic fertilization treatment, followed by inorganic (approx. 590 seeds per panicle) and control (approx. 170 seeds per panicle). Furthermore, she reported that among fertilization treatments, dry weight per stem was actually affected. The highest dry weight per stem (approx. 5 g) obtained in organic fertilization, while the lowest were found under inorganic fertilization (approx. 3.2. g) and control (approx. 2.6 g). Finally, she demonstrated that organic fertilization had better impact on some agronomic characteristics, especially on plant biomass, and argued that further research is necessary to provide safe conclusions on the adaptability and performance of teff under Mediterranean conditions.

Camelina

Camelina (*Camelina sativa* (L.) Crantz) (Fig. 3), also known as false flax or gold of pleasure, is a cruciferous annual or summer oil seed plant originated from the Mediterranean and Central Asia (Zubr, 1997; Ionescu and Roman, 2009). It has been cultivated in Europe for centuries and is used as the most important oil crop from the Bronze and Iron Ages until the beginning of the Industrial Revolution (Ionescu and Roman, 2009). Recently, the interest in camelina has been renewed due to its very low requirements for tillage and weed control

Fig. 2. Teff crop one month before harvest (July, 2015) in the experimental field of Agricultural University of Athens (Chroni, 2016)

Fig. 3. Established camelina crop before passing into the maturity stage (June 2016) in Greece (Agricultural University of Athens) (Kobilakou, 2017)

(Budin *et al*., 1995; Abramovič and Abram, 2005). The crop is now being researched due to high α-linolenic acid (38%) content of its oil (Zubr, 1997). Alpha-linolenic acid is a nutritionally valuable omega-3 fatty acid which is generally found in significant quantities only in linseed and fish oils (Crowley and Fröhlich, 1998) and can reduce the incidence of cardiovascular disease as well as various health risks in humans (Ruxton *et al*., 2007). Camelina oil also is high in omega-6 fats (linoleic acid, approx. 15-20%), vitamin E (approx. 110 mg/100g) and natural antioxidants such as tocopherols (Ionescu and Roman, 2009). Therefore, camelina offers an opportunity to supply the growing demand for high quality edible oils (Zurb, 1997).

In Greece, a field trial was conducted with the aim of investigating the effect of different fertilization regimes [control, inorganic fertilization (fertilizer 34.5-0-0 with 200 kg N ha^{-1}), compost (8000 kg ha^{-1}) and farmyard manure (18000 kg ha^{-1})] on growth and yield of camelina crop (Kobilakou, 2017). The results revealed that fertilization had a significant effect on yield and yield parameters such as thousand-seed weight. The maximum values (approx. 1820 kg ha^{-1} and 1.35 g for seed yield and thousand-seed weight, respectively) were recorded with compost, followed by inorganic fertilization (approx. 1350 kg ha^{-1} and 0.81 g), control (approx. 1150 kg ha^{-1} and 0.80 g) and farmyard manure (approx. 830 kg ha^{-1} and 0.73 g). In the conclusions of this study, she mentioned that compost increased the yield of camelina and suggested further studies on the performance of camelina under different types and rates of fertilizers.

Flax

Flax or linseed (*Linum usitatissimum* L.) is the only species of Linaceae family that has economic as agronomic values (Copur *et al*., 2006) and is one of the oldest cultivated crops that continues to be widely grown for oil, fiber and food (Berglund, 2002). It originates from Europe and Southern Asia (Casa *et al*., 1999). The fiber, obtained from stems, is used to make fine linen and paper. Flax seed is a rich source of oil (41%), proteins (20%) and total dietary fiber (28%) and contains 7.7% moisture and 3.3% ash (Morris, 2007). In the past, the main use of flax oil was as a raw material for varnish, paints, linoleum and oilcloth industry, inks, leather and soaps (Laza and Pop, 2012). Flax oil has become popular for its nutritional and pharmaceutical values (Zhang *et al*., 2011). Nowadays, it is used in human consumption, medical purposes and animal feed (Laza and Pop, 2012). Flax oil is commonly known as the richest source of omega-3 fatty acid, α-linolenic acid, which is one of the essential fatty acids (Madhusudhan, 2009). Several studies have shown that flax oil has a positive impact on many diseases, such as hyperlipidemia, colon tumor, mammary cancer and atherosclerosis (Zhang *et al*., 2011).

In a 2-year field experiment in the experimental field of Agricultural university of Athens, Greece, the influence of different tillage systems [conventional tillage (CT), minimum tillage (MT), no-tillage] and organic fertilization (vetch as green manure, faba bean as green manure and compost at a rate of 2500 kg ha^{-1}) on growth and yield of flax were determined (Bilalis *et al*., 2010). It was observed that tillage system had significant effect on seed yield and oil yield. The highest values (1761 and 670 kg ha^{-1} for seed yield and oil yield, respectively) were obtained under minimum tillage system. The fertilization and especially the vetch and faba bean green manure had a significant influence on the oil content of the flax. Oil content (39.34%) was significantly higher in plots fertilized with faba bean green manure. Finally, the researchers of this study reported that conservation tillage systems could increase the oil yield of flax.

Emmer Wheat

Emmer (*Triticum turgidum* L. ssp. *dicoccon* (Schrank) Thell.) is a primitive hulled allotetraploid wheat species developed from its correspondent wild form [*Triticum dicoccoides* (Koern. ex Asch. et Graebn.) Schweinf.] (Pagnotta *et al*., 2009; Özbek *et al*., 2012). It originates from Middle East (Iran, Iraq, Jordan, Syria, Palestine) and during the last century, the introduction of high-yielding and freethreshing wheats led to the decline of emmer cultivation in mountain regions and small areas of Mediterranean basin (Italy, Spain), Ethiopia, Iran, Transcaucasia, Central Europe, India and the Volga Basin (Marino *et al*., 2009; Pagnotta *et al*., 2009; Zaharieva *et al*., 2010). Nowadays, emmer accounts for 1% of the total world area cultivated with wheats. In ancient times, it was the main crop of Babylon, ancient Egypt and Greece (Zaharieva *et al*., 2010). Emmer is rich in protein (18-23%), minerals and fiber (Marino *et al*., 2011). The findings of recent surveys demonstrated that emmer is a very healthy cereal, suitable for diets of people suffering from allergies, colitics, and high blood cholesterol (Marino *et al*., 2011). Moreover, it is characterized by the resistance to pest and disease, the tolerance to abiotic and biotic stress, the quality of seed protein and the high concentration of micronutrients such as Zn, Fe, and Mn (Marino *et al*., 2009; Zeharieva *et al*., 2010).

In Italy, a research study was carried out to evaluate the influence of olive pomace compost [fertilization treatments (each of them at a rate 80 kg N ha^{-1}): commercial organic mineral fertilizer (control), olive pomace compost A1 (OPC-A1) (composting mixture with C/N ratio of 45 stopped at the end of active phase of bio-oxidation), olive pomace compost A2 (OPC-A2) (composting mixture with C/N ratio of 45 processed until maturation), olive pomace compost B1 (OPC-B1) (composting mixture C/N ratio of 30 stopped at the end of active phase) olive pomace compost B2 (OPC-B2) (composting mixture with C/N ratio of 30 processed until maturation)]on growth, yield and quality of emmer wheat (Diacono *et al*., 2012). They observed that different fertilization treatments had no significant effect on growth and yield of emmer, however, they found that olive pomace compost showed an increase of 9.8% in grain yield compared to commercial mineral fertilizer treatment. The emmer grain protein was significantly affected by fertilization with the highest values obtained in the commercial mineral fertilizer (12.30%) and matured compost with low C/N ratio (12.25%) treatments. Finally, they demonstrated that more experiments and data are needed to evaluate the possible long-term effects of olive pomace compost in the emmer crop.

Conclusions

Several studies, conducted under Mediterranean semi-arid conditions and organic cropping system, have proved that innovative crops can also be grown for alternative uses. Quinoa and chia could be successfully used in animal feed. Moreover, quinoa could be exploited as a medicinal plant due to saponins extracted from seed coats. Nigella and camelina seeds contain oils which can have several uses in pharmaceutical and food industries. Flax seed oil is rich in omega-3 fatty acids and can be accepted in the diets designed for specific health benefits. Emmer wheat has the potential for developing new health food products. According to the literature, it has been observed that innovative crops cultivated under organic system present better quality and similar yields as with those cultivated under conventional system, and in some cases, even higher. Taking all these into account, organic agriculture could also be characterized as innovative and not only as traditional.

Table 1. Innovative crops cultivated under Mediterranean conditions and their uses

Crop Species	Growing Country	Uses of Crop	Citations
Quinoa	Greece	Seed	Bilalis *et al*., 2012
		Saponin	Bilalis *et al*., 2012
		Fodder	Kakabouki *et al*., 2014
			Papastylianou *et al*., 2014
	Italy	Seed	Pulvento *et al*., 2010
	Turkey	Seed	Geren, 2015
Chia	Greece	Fodder	Bilalis *et al*., 2016
	Italy	Seed	Bochicchio *et al*., 2015
Nigella	Greece	Seed	Roussis *et al*., 2017
	Turkey	Oil	Kizil *et al*., 2008
Teff	Greece	Seed	Chroni, 2016
		Fodder	Chroni, 2016
Camelina	Greece	Oil	Kobilakou, 2017
	Italy	Oil	Masella *et al*., 2012
Flax	Greece	Oil	Bilalis *et al*., 2010
	Italy	Fibre	Rossini and Casa, 2003
Emmer Wheat	Italy	Seed	Diacono *et al*., 2012

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