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# Adaptation of oat (*Avena sativa*) cultivars to autumn sowings in Mediterranean environments

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ABSTRACT

Oat (*Avena sativa* L.) is a cereal widely grown as a spring crop throughout the temperate zones, being particularly adapted to areas with cool and wet summers such as Northwest Europe and Canada. There is scope for further oat expansion in Mediterranean Basin where the crop will face hot and dry weather. In this work, we assessed adaptation of 32 modern oat cultivars from different origin and usage to autumn sowings under Mediterranean agroecological conditions. Experiments were carried out over four crop seasons at 6 contrasting locations along Mediterranean Basin, including Spain, Tunisia, Egypt and Palestinian Territories. ANOVA analysis revealed genotype × environment interactions. For test environment and genotype evaluation heritability-adjusted genotype plus genotype × environment (HA-GGE), biplot analysis was performed. Biplot analysis differentiate two mega-environments one comprising the locations of Egypt and Palestinian Territories and another including Spain and Tunisia. Pearson's correlation and HA-biplots confirmed overall a positive correlation between yield and HI, and a negative correlation between yield and rust and flowering date. For other traits, relations among the traits differed depending on the ME evaluated. The study allowed determining within each ME the best discriminative location, representative of the target environment and repeatable across year and the genotypes with superior and stable characteristic for breeding of adapted oats.



## 1. Introduction

Oat (*Avena sativa* L.) is an important multi-purpose cereal crop cultivated for grain, feed, fodder and straw over more than 9 million hectares globally (FAO, 2011). Oats are mostly grown in cool moist climates and they can be sensitive to hot, dry weather between head emergence and maturity. For these reasons, world oat production is generally concentrated between latitudes 35 and 65° N. Traditionally oats have been cultivated in cropping areas not appropriate for wheat, barley or maize and the cultivated area maintained stable over the years. Due to its good adaptation to a wide range of soil types and because on marginal soils oats can perform better than other small-grain cereals, there is an increasing interest to expand oat cultivation to southern countries and even to subtropical areas (Buerstmayr et al., 2007; Løes et al., 2007; Ren et al., 2007; Stevens et al., 2004; Forsberg and Reeves, 1995; Hoffmann, 1995). In fact, autumn sown oat is increasing in Australia (Armstrong et al., 2004), south of Japan (Katsura, 2004), south China (Wan, 2004) and temperate areas of South America (Federezzi and Mundstock, 2004). These environments are characterized by mild and moderately rainy winters and warm and dry springs being winter sowing of spring crops a common practice. Thus, both grain and forage oats may be well suited to Mediterranean climates and farming systems.

Increase of *A. sativa* cultivation in these rainfed Mediterranean environments will predictably encounter water limitations as well as disease incidence such as the crown rust (*Puccinia coronata* f.sp. *avenae*). Crown rust causes high losses in yield and grain quality worldwide (Simons, 1985) but particularly in the Mediterranean Basin where rust populations are more virulent than in the centre and north of Europe (Herrmann and Roderick, 1996). Crown rust can be controlled with fungicides but this is relatively expensive and harmful due to its negative effects on human health and environment. Consequently, host resistance is being explored as the most effective, economical and environmentally friendly control method (Stevens et al., 2004). However, resistance obtained is often overcome by emerging pathogenic races. This is mainly due to the

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inappropriate use of resistance sources, of monogenic nature. Thus, it is necessary to identify novel sources of resistance that show durable resistance over time and in different environments.

Water limitation is also a feature of the Mediterranean environments. Thus, adaptation to Mediterranean conditions implies the development of drought tolerance, particularly in rainfed crops in marginal areas such as oat. The selection of adequate drought tolerant genotypes is strongly affected by the genotype × environment interaction (GEI) (Ceccarelli, 1996). Given the difficulty of selecting drought tolerant genotypes, multi-environment yield trials (MEYTs) are used in the final selection cycles to identify superior genotypes for use in plant breeding programmes. GEI attenuates the association between phenotype and genotype, reducing genetic progress in plant breeding programmes so the knowledge of how GEI affect the performance of a given cultivar may aid in selecting cultivars and their best environments for maximum yield. Through additive models of the ANOVA is it possible to describe the main effects of genotype and environment and determine whether GEI is a significant source of variation. However, it does not provide insights into the genotypes or environments that give rise to the interaction (Samonte et al., 2005). Regression approaches (Eberhart and Russell, 1966; Tai, 1971), variance component methods (Shukla, 1972), additive main effects and multiplicative Interaction (AMMI) analysis (Gauch and Zobel, 1997; Gauch et al., 2008; Gauch, 1992), yield stability statistic approaches (Kang, 1993) and GGE biplot analysis (Yan and Kang, 2003; Yan and Tinker, 2006; Yan, 2001) are major techniques in analyzing multi environmental trails. However, the AMMI model and GGE biplot analysis are between the most frequently used in recent years in part due to the graphical and visual analysis they offer particularly desirable when dealing with complex data structures and patterns (Gauch et al., 2008). AMMI, GGE and other SVD-based model families share some common features, but best practices require model diagnosis for each individual dataset to determine which member is most predictively accurate (Gauch, 2006). Here, GGE have been designed for conducting biplot analysis of research data (Yan et al., 2000, 2007). GGE stands for genotype main effect (G) plus genotype by environment interaction (GE), which is the only source of variation that is relevant to cultivar evaluation, allowing visual examination of the GEI pattern of MEYT data. Thus, mathematically, GGE is the genotype by environment data matrix after the environment means are subtracted. GGE analysis have been previously prove useful to identify and characterize disease resistance and yield stability of breeding material in field trials (Villegas-Fernández et al., 2009; Fernández-Aparicio et al., 2012; Rubiales et al., 2012; Flores et al., 2012, 2013) taking advance of the discrimination power vs. representativeness view of the GGE biplot effective in evaluating test environments.

In this work following recording of several agronomic and disease related traits and through GGE approaches we aimed to (1) determine the usefulness of the different locations for selection of superior oat genotypes with interesting agronomic traits and (2) identify oat germplasm with good adaptation to Mediterranean agroecological conditions, with special attention to the stability of yield and of resistance to crown rust across locations distributed over the Mediterranean Basin.

## 2. Materials and methods

### 2.1. Plant material and experimental design

An Oat Network consisting of 32 commercial varieties considered with potential under Southern Spanish conditions were supplied by the Andalusian Network of Agricultural Experimentation (RAEA) and were evaluated over four crop seasons at 6 contrasting locations along Mediterranean Basin, including field trials conducted in Spain, Egypt, Palestinian Territories and Tunisia. An environment was the combination of a year and location (Table 1). The cultivars studied were named in this study by the following numbers: (1) Acebeda, (2) Adamo, (3) Aintree, (4) Alcudia, (5) Anchuela, (6) Araceli, (7) Caleche, (8) Canelle, (9) Chambord, (10) Chapline, (11) Charming, (12) Condor, (13) Cory, (14) Edelprinz, (15) Flega, (16) Fringante, (17) Fuwi, (18) Hamel, (19) Kankan, (20) Kantora, (21) Karmela, (22) Kassandra, (23) Kazmina, (24) Mirabel, (25) Mojacar, (26) Orblanche, (27) Pallidi, (28) Patones, (29) Prevision, (30) Primula, (31) Rapidena, and (32) Saia (Supplemental Table 2). Cultivars were developed by different institutions and/or companies (Supplemental Table 1) and released to the market in the last 20 years. Most of these cultivars were bred for the north-European agroclimatic conditions, since the oat crop has been traditionally considered as a cold adapted cereal crop. However, scare information is available about their field performance under the agroclimatic conditions of the Mediterranean area.

Palestinian trials were performed in a single-location (Tulkarm) over the growing seasons 2007–2008, 2008–2009 and 2009–2010 on a light clay chromic luvisol (FAO, 2011) experimental field; Egyptian trials were carried out in a single-location (Kafr El-Sheikh) over the growing seasons 2007–2008 and 2008–2009 on a loamy calcaric fluvisol (FAO, 2011) experimental field; Tunisian trial was done in a single-location (Beja), in the season 2007–2008 on a clay loam rendric leptosol (FAO, 2011) experimental field; Spanish trials were performed in three contrasting locations (Escacena with light clay eutric vertisol, Córdoba with light clay calcic cambisol and Salamanca with sandy loam or sandy-clay-loam Vertic Luvisol soils, respectively) during growing seasons 2009–2010 and 2010–2011 (Table 1). Sowings took place between October and December, according to local practices, except in Córdoba during the season 2009–2010 in which, due to intense rain levels, the sowing took place in January. No irrigation was performed in Palestinian, Spanish or Tunisian trials, but Egyptian plots were level basin flood irrigated according to local practise. This was done at sowing, and then on 1st of February and 1st of March by the application of 800 $m^3$ $ha^{-1}$ each time. No artificial inoculation was performed at any location, infection occurring naturally. At each location, a randomized complete block design with three replicates was used. Each replicate consisted in independent plots consisting in three 1 m-long rows bordered by the rust-susceptible oat cultivar Cory with the aim of providing the most appropriate conditions for the disease development. Within each plot, the rows were separated from each other 30 cm, at a sowing density of around 90 seeds $m^{-2}$. Hand weeding was carried out when required, and no herbicides or fertilizers were applied.

### 2.2. Disease, precocity, biomass and seed yield assessments

When disease symptoms were observed, disease severity (DS) was assessed as a visual estimation of the percentage of whole plant tissue covered by pustules of the crown rust. Observations were made weekly from disease onset until the end of the disease cycle. This allowed calculation of the area under the disease progress curve (AUDPC) according to Wilcoxson et al. (1975). Precocity was estimated as days to flowering by counting the number of days from sowing until 50% anthesis. At maturity stage, total above-ground dry matter was determined following field-drying of the plant material for at least 1 week. All grain was oven-dried at 70 °C. Yield are presented on an oven-dry basis of seeds weighted (kg/ha). Biomass data based on the above-ground plant weight (tones/ha) was taken for Spanish and Palestinian trials and harvest index (HI, %) was calculated as the ratio between grain weight to total dry matter.