Elevated temperature affects vegetative growth and fruit oil concentration in olive trees (*Olea europaea*)

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Abstract

Temperature is one of the main factors that regulates the growth and development of crops and determines their yield. In recent decades, there has been an increase in global temperature, which represents a challenge for olive production. Olive trees in Argentina are grown over a wide range of latitude and altitude, and it has been observed in warmer areas of the country that some cultivars have lower yields and greater vegetative growth than in their regions of origin in the Mediterranean Basin. Thus, the aim of this study was to evaluate the effect of elevated temperature on the vegetative growth and fruit oil concentration of two olive (*Olea europaea*) cultivars by directly manipulating temperature. The experiment was conducted at an experimental station in the province of La Rioja in northwest Argentina. Two temperature levels (a control and a heated treatment; 3 °C above the control) were applied from fruit set until final harvest using open top chambers (OTC) with electronically controlled heating systems. The responses after one season of treatment for potted 'Coratina' and 'Arbequina' trees are shown here. Whole tree leaf area was significantly greater in the heated OTC than in the control OTC for both cultivars. Shoot elongation showed a similar tendency, but the apparent difference was not statistically significant. In contrast, elevated temperature had a negative effect on fruit dry weight and oil concentration in both cultivars. Elevated temperature reduced fruit dry weight by 0.34 and 0.22 g in 'Coratina' and 'Arbequina', respectively. Additionally, fruit oil concentration (%) was 4.6 and 6.2 % less on a dry weight basis in fruit that received elevated temperatures. The results indicate that elevated temperature promotes vegetative growth and negatively affects oil concentration in olive trees under our climate conditions.

Keywords: 'Arbequina', 'Coratina', fruit dry weight, heating systems, open top chamber

INTRODUCTION

Most olive production in Argentina is located at subtropical latitudes under climatic conditions that differ markedly from those of the Mediterranean Basin where most commercial cultivars have originated (Searles et al., 2011). At these low latitudes, some cultivars appear to have higher vegetative growth and lower oil concentrations than in the Mediterranean (Correa-Tedesco et al., 2010; Rondanini et al., 2014). However, the climatic variables that are associated with these potential responses have not been well studied.

Temperature is one of the most important factors that affects the growth and yield of crop plants, and is likely to be of increasing importance with global change (DaMatta et al., 2010; Lobell et al., 2011). In olive, most temperature-related studies have focused on the requirements of chilling hours and on flowering phenology (e.g., De Melo-Abreu et al., 2004; Aybar et al., 2015). Recently, Vuletin-Selak et al. (2013) found that increasing temperature in the field led to earlier full bloom and a shortened flowering period. Less information is available concerning the response of olive growth to temperature, although Perez-Lopez et al. (2008) proposed a base temperature of 7 °C for trunk growth and 13 °C for shoot elongation.

From correlation studies where a range of temperature conditions was obtained over several years and/or locations, fruit oil concentration and oleic acid content have been shown to decrease in many cultivars with increasing temperature (Rondanini et al., 2011; Trentacoste et al., 2012; Rondanini et al., 2014). These correlative studies were corroborated by directly manipulating branch temperature during the four months of olive oil accumulation following fruit set (García-Inza et al., 2014). Oil concentration in the manipulative experiment was found to decrease linearly at a rate of 1.1% per °C between average seasonal temperatures ranging from 16–32 °C.

Analyzing the response of vegetative and reproductive growth to temperature at the whole tree level could provide further agronomic insights and contribute to our understanding of global warming. Thus, our objective was to evaluate the effect of elevated temperature on vegetative growth and fruit oil concentration of two olive cultivars (cvs. 'Arbequina, 'Coratina') by directly manipulating temperature in open top chambers (OTC).

MATERIALS AND METHODS

Experimental site, treatments, and experimental design

The experiment was conducted during the 2014-15 growing season at the field station of CRILAR-CONICET, located in the town of Anillaco in La Rioja, Argentina (28° 48' S lat., 66° 56' W long.; 1325 masl). The trees (cvs. 'Arbequina' and 'Coratina') were two years-old at the start of the experiment and were grown in 40 l pots. The temperature treatments were implemented from final fruit set (approx. 60-70 days after full bloom) until the end of oil accumulation (December 2014-April 2015). The two temperature levels employed using open top chambers (OTC) were a control (T0), which was near ambient temperature, and 3 °C above the control (T+). The measurements reported in this study were conducted on two trees within each chamber.

The experimental design was a completely randomized block design with each of the four blocks containing four OTC (i.e., a total of 16 OTC). Each OTC within a block represented one of the four different treatment combinations used: 1) cv. 'Arbequina' at T0, 2) cv. 'Arbequina' at T+, 3) cv. 'Coratina' at T0, and 4) cv. 'Coratina' at T+.

Heating system

Each OTC was 1.5 m wide by 2.0 m high, built of structural pipe, and closed on its sides with transparent plastic (100μm polyethylene, Agroredes, Argentina). Clear acetate strips 30-cm wide were also placed on each of the four sides of the T+ chamber roofs in order to reduce the size of the upper opening for greater efficiency in heat conservation. The T+ chambers were heated using two complementary heating systems: 1) a transparent polyethylene tunnel 8-m long, containing painted black stones, served to heat the circulating air during daylight hours; and 2) an electric heater (2000 W, ATMA, Argentina) provided heat whenever the temperature difference between T0 and T+ was less than the set value. The electric heater and the stone tunnel converged into a single forced air outlet into the chamber through a set of PVC tubes and connectors. The temperature inside each OTC was recorded every 15 min by a data logger (Cavadevices, Argentina) in order to maintain the difference between T0 and T+ close to 3 °C by electronically turning the electric heaters on/off. Thus, a fixed temperature differential between chambers was guaranteed, ensuring that the conditions within the T+ chambers oscillated in tune with the daily cycle of ambient temperature. Air movement through both the T0 and T+ chambers was accomplished by forcing air intake from outside the OTC using a fan attached to a PVC tube. This helped to maintain air temperature near ambient in the T0 chambers.

Response variables

Fruit number per tree, individual fruit dry weight, and oil concentration (%) were the reproductive growth variables evaluated at the end of the season. Fruit number was calculated as the total yield per tree divided by the fresh weight of a sample of 50 fruit per tree. The same sample was then dried in an oven at 70 °C to constant weight for individual fruit dry weight determination. Oil concentration on dry weight basis was determined by nuclear magnetic resonance (SLK-200, Spinlock, Argentina) with corresponding calibration curves for each of the cultivars.

At the end of the season, shoot elongation, leaf area per tree, and trunk diameter growth were measured. Apical shoot elongation was determined on four previously selected one year-old shoots per OTC with similar fruit load, while leaf area per tree was obtained by defoliating the trees in the laboratory and estimating leaf area from leaf dry weight. Trunk diameter was measured using an electronic caliper at 20 cm above ground level.

Complementary environmental measurements

In addition to the temperature data obtained from each OTC, relative humidity (RH) and CO_2 concentration were measured every 15 min and recorded in a data logger for one T0 and one T+ chamber. Similar measurements of temperature, RH, and CO_2 were conducted under ambient conditions outside of the chambers. Photosynthetically active radiation (PAR) was also recorded inside and outside of the OTC.

Statistical analyses

Statistical analysis was performed using standard models of ANOVA for completely randomized block designs (Infostat software, Cordoba, Argentina). The Fisher LSD test was used to determine significant differences between treatments ($P \leq 0.05$). The graphs were illustrated with GraphPad 5.01 (GraphPad Prism Software, Inc., La Jolla, CA, USA).

RESULTS AND DISCUSSION

There have been few manipulative field experiments of temperature using whole plants in woody fruit species (e.g., Sadras et al., 2012; Vuletin-Selak et al., 2014). Under our experimental conditions, the average air temperature was 22.8 °C in the T0 chambers, and 25.6 °C in T+ chambers, nearly 3 °C above the T0 (Table 1). This difference is within the natural range of variation of the average daily temperature in our olive production region due to variations between years and locations (Rondanini et al., 2014). In addition, daily temperature fluctuations within the OTC oscillated with the ambient temperature, so there were no changes in thermal amplitude (data not shown). The relative humidity was 5.5% lower in the T+ chambers than in the T0 chambers and 9.7% lower than the ambient temperature outside the OTC. This decrease in relative humidity was largely a function of the increase in temperature in the T+ OTC. The photosynthetically active radiation (PAR) inside both the T0 and T+ OTCs was 78% of ambient due to some PAR absorption by the polyetheylene plastic of the OTC. The CO_2 concentration was similar to the environment outside the OTCs in both thermal treatments.

In our experiment, fruit number per tree at harvest showed significant differences between cultivars but not between the T0 and T+ chambers (Figure 1A), probably because the heating started once fruit number was established at the end of fruit set. Fruit dry weight showed an interaction between cultivar and thermal treatment at final harvest, with cv. 'Coratina' showing a greater absolute reduction in weight than cv. 'Arbequina' (Figure

1B). This response to temperature concurs with smaller olive fruit being found at lower elevation and warmer temperatures than at higher elevation and lower temperatures in commercial orchards in northwestern Argentina (Rondanini et al., 2014). In addition, García-Inza et al. (2014) reported that fruit dry weight of cv. 'Arauco' decreased linearly with temperature when average daily temperature was above 25 °C when the temperature of individual reproductive branches was directly manipulated. Trentacoste et al. (2012) did not observe a relationship between fruit weight and temperature in ten cultivars, but the average temperatures were much lower. Fruit oil concentration (%) on a dry weight basis was also negatively affected by heating. Oil concentration decreased 6.2% points in the T+ fruit of 'Arbequina' and 4.6% for 'Coratina' (Figure 1C). These decreases represent approximately 2% less oil per °C. An analisis of six olive cultivars at three locations over two years observed a decrease of 3% per °C (Rondanini et al., 2014).

In contrast, the leaf area of the T+ trees was significantly greater than that of the T0 trees in both cultivars by 20 to 30% (Figure 1D). The apical shoot elongation during the experimental period showed a similar tendency, although there was no statistically significant difference between the thermal treatments (Figure 1E). It is likely that much of the overall tree shoot elongation and leaf area expansion occurred early in the season during fruit set and early fruit growth before heating was started. In our experiment, fruit load was high considering tree size and likely limited photoassimilate availability for shoot growth in the latter part of the season (Fernández et al., 2015). Greater vegetative responses to heating would be anticipated if the heating was done early in the season as has been described in grape (Keller and Tarara, 2010). Trunk diameter growth showed no significant differences between cultivars or thermal treatments (Figure 1F).

CONCLUSIONS

Final fruit weight and oil concentration (%) were negatively affected in both olive cultivars by heating (+3 °C) young olive trees in OTCs during oil accumulation, while vegetative growth mostly increased. These preliminary results suggest that a change in the balance between reproductive and vegetative growth may occur under some global warming scenarios.

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Literature cited

Aybar, V.E., De Melo-Abreu, J.P., Searles, P.S., Matias, A.C., Del Rio, C., Caballero, J.M., and Rousseaux, M.C. (2015). Evaluation of olive flowering at low latitude sites in Argentina using a chilling requirement model. Spanish J. Agric. Res. 13, 1–10 http://dx.doi.org/10.5424/sjar/2015131-6375.

Correa-Tedesco, G., Rousseaux, M.C. and Searles, P.S. (2010). Plant growth and yield responses in olive (Olea europaea) to different irrigation levels in an arid region of Argentina. Agric. Water Manage. 97, 1829–1837 http://dx.doi.org/10.1016/j.agwat.2010.06.020.

DaMatta, F.M., Grandis, A., Arenque, B.C. and Buckeridge, M.S. (2010). Impacts of climate changes on crop physiology and food quality. Food Res. Int. 43, 1814–1823 http://dx.doi.org/10.1016/j.foodres.2009.11.001.

De Melo-Abreu, J.P., Barranco, D., Cordeiro, A.M., Tous, J., Rogado, B.M. and Villalobos, F.J., 2004. Modelling olive flowering date using chilling for dormancy release and thermal time. Agric. For. Meteorol. 125, 117–127 http://dx.doi.org/10.1016/j.agrformet.2004.02.009.

Fernández, F.J., Ladux, J.L. and Searles, P.S. (2015). Dynamics of shoot and fruit growth following fruit thinning in olive trees: Same season and subsequent season responses. Sci. Hortic. 192, 320–330 http://dx.doi.org/10.1016/j.scienta.2015.06.028.

García-Inza, G.P., Castro, D.N., Hall, A.J. and Rousseaux, M.C. (2014). Responses to temperature of fruit dry weight, oil concentration, and oil fatty acid composition in olive (*Olea europaea* L. var. 'Arauco'). Eur. J. Agron. 54, 107–115 http://dx.doi.org/10.1016/j.eja.2013.12.005.

Keller, M. and Tarara, J.M. (2010). Warm spring temperatures induce persistent season-long changes in shoot development in grapevines. Ann. Bot. 106, 131–41 http://dx.doi.org/10.1093/aob/mcq091.

Lobell, D.B., Schlenker, W. and Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. Science 333, 616–20 http://dx.doi.org/10.1126/science.1204531.

Pérez-López, D., Ribas, F., Moriana, A., Rapoport, H.F. and De Juan, A. (2008). Influence of temperature on the growth and development of olive (*Olea europaea* L.) trees. J. Hortic. Sci. Biotechnol. 83**,** 171–176 http://dx.doi.org/10.1080/14620316.2008.11512366.

Rondanini, D.P., Castro, D.N., Searles, P.S., and Rousseaux, M.C. (2011). Fatty acid profiles of varietal virgin olive oils (*Olea europaea* L.) from mature orchards in warm arid valleys of Northwestern Argentina (La Rioja). *Grasas y Aceites, 62,* 399-409 http://dx.doi.org/10.3989/gya.125110.

Rondanini, D.P., Castro, D.N., Searles, P.S., and Rousseaux, M.C. (2014). Contrasting patterns of fatty acid composition and oil accumulation during fruit growth in several olive varieties and locations in a non-Mediterranean region. Eur. J. Agron. 52, 237–246 http://dx.doi.org/10.1016/j.eja.2013.09.002.

Sadras, V.O., Bubner, R. and Moran, M.A. (2012). A large-scale, open-top system to increase temperature in realistic vineyard conditions. Agric. For. Meteorol. 154–155, 187-194 http://dx.doi.org/10.1016/j.agrformet.2011.11.005.

Searles, P.S., Agüero Alcarás, M., Rousseaux, M.C., (2011). Consumo del agua por el cultivo del olivo (*Olea europaea* L.) en el noroeste de Argentina: una comparación con la Cuenca Mediterránea. Ecol. Austral 21, 15–28

Trentacoste, E.R., Puertas, C.M. and Sadras, V.O. (2012). Modelling the intraspecific variation in the dynamics of fruit growth, oil and water concentration in olive (*Olea europaea* L.). Eur. J. Agron. 38, 83–93 http://dx.doi.org/10.1016/j.eja.2012.01.001.

Vuletin Selak, G., Perica, S., Goreta Ban, S. and Poljak, M. (2013).The effect of temperature and genotype on pollen performance in olive (*Olea europaea* L.). Sci. Hortic. 156**,** 38–46 http://dx.doi.org/10.1016/j.scienta.2013.03.029.

Vuletin Selak, G., Cuevas, J., Goreta Ban, S., Pinillos, V., Dumicic, G. and Perica, S. (2014). The effect of temperature on the duration of the effective pollination period in 'Oblica' olive (*Olea europaea*) cultivar. Ann. Appl. Biol. 164, 85–94 http://dx.doi.org/10.1111/aab.12082.

Table 1. Average mean daily temperature, relative humidity (RH), CO_2 concentration, and average incident photosynthetically active radiation (PAR) measured outside the OTC (ambient), and inside the control (T0) and heated (T+) OTC. Data correspond to the average between final fruit set (December 1, 2014) and final harvest at the end for fruit growth (April 20, 2015)

Temperature treatment	Temperature (ºC)	Relative humidity (%)	CO_2 Conc. (ppm)	Incident PAR (mol m^{-2} dia^{-1})
Ambient	22.2	62.0	419.1	40.1
Control (T0)	22.8	57.8	420.7	31.3
Heated (T+)	25.6	52.3	421.7	31.3
Diff. between treatments[1]	2.8	-5.5	1.0	0.0

[1] Difference between the T0 and T+ OTC

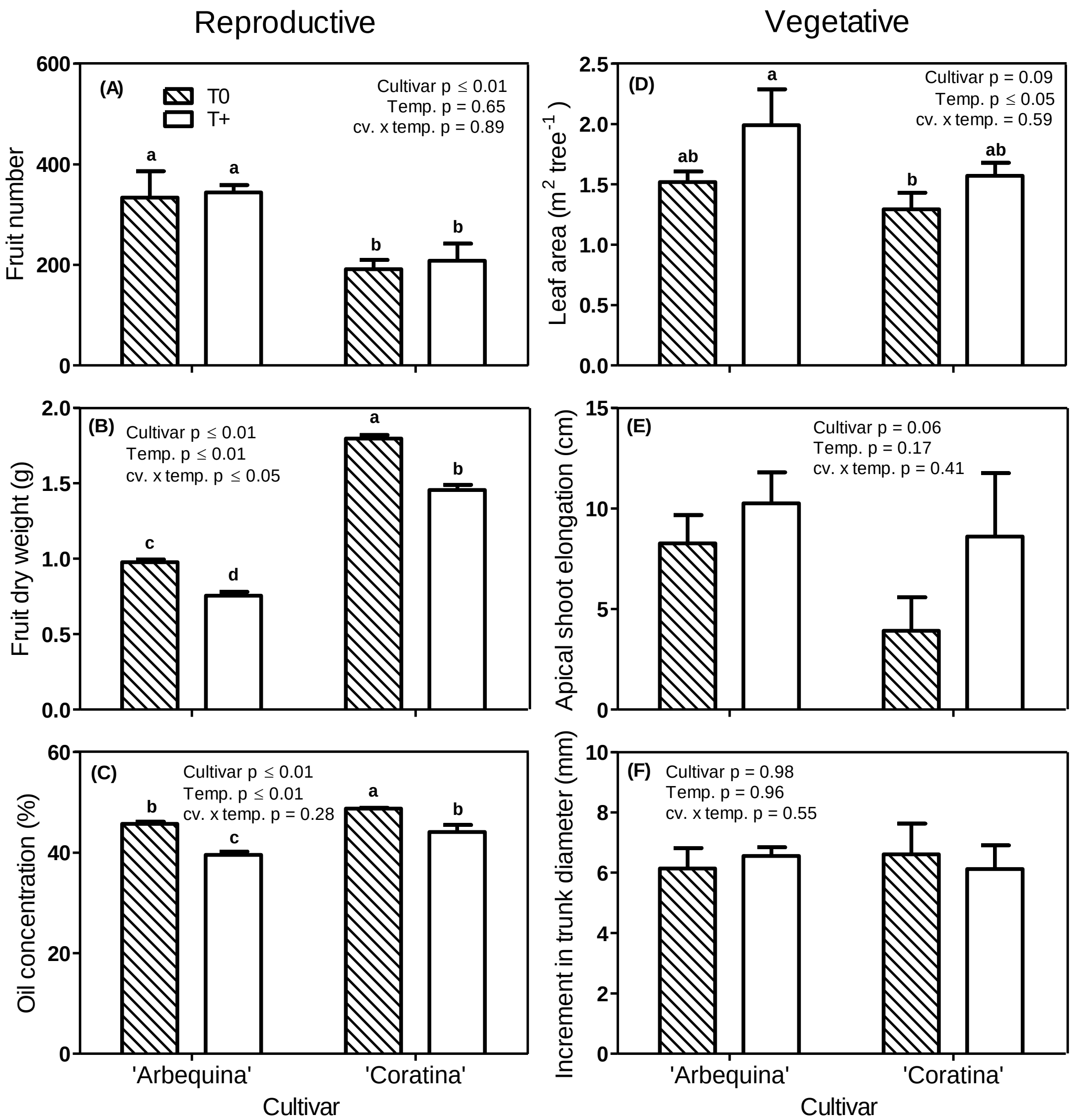

Figure 1. Reproductive and vegetative growth responses to heating as measured at final harvest in cv. 'Arbequina' and 'Coratina'. Fruit number (A), individual fruit dry weight (B), and fruit oil concentration (C) were the reproductive growth variables measured. Leaf area per tree (D), apical shoot elongation (E), and increment in trunk diameter (F) were the vegetative growth variables assessed. The experimental groups were control (T0) and heated (T+, 3 ºC above control), and were applied from December 2014 until Abril 2015. Each point represents the mean ± the standard error (n=4). Different letters above bars indicate significant differences ($p \leq 0.05$) between treatments.