Olive Productive Oil

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Olive (Olea europaea L.) is well adapted to the environmental conditions of the Mediterranean Basin, agricultural techniques and breeding through selection programs will have to adapt to these climate change, threatening to worsen in the near future.

Olea europaea | olive oil | heat stress | fruit production | high temperatures

1. Introduction

The picture emerging from a review of recent studies may be seen as foretelling agricultural techniques and future breeding and selection programs, designating specific olive cultivars that are more resistant to high temperatures. The olive (*Olea europaea* L.) is a crop well adapted to the environmental conditions prevailing in the Mediterranean Basin. Nevertheless, climate change occurring in the last decade and threatening to worsen in the future, with elevated temperatures throughout the year, affect many stages of the reproductive growth and development of olives as well as oil quality at harvest [1]. Defining the pathways controlling high fruit productivity and oil quantity and quality, despite elevated temperatures and sub-optimal growing conditions, is important for coping with current and predicted climate change.

Abiotic stresses are often interrelated in causing morphological, physiological, biochemical, and molecular changes that adversely affect plant growth and productivity and ultimately lead to reduced yield [2]. More specifically, the effect of high temperature environments on olive oil yield and quality is of increasing concern. The sexual reproductive phase in plants has been proven to be vulnerable to the negative effects of high temperatures stress [3]. In the Northern Hemisphere, olive trees go through flower induction during December and January (“winter”), Anthesis, pollination and fruit set during March to May (“spring”). The fruits accumulate oil from June to November [4]. Thermal conditions closely regulate all phases of the plant’s life cycle [5]. Elevated temperatures may affect each of the above processes. Warm winters may affect flower induction; a warm spring may affect pollen grain and pistil viability, as cell division/expansion during fruit development may be affected by warm summers. An unusually warm summer may also affect oil accumulation and oil quality at harvest [1]. As global changes increase in intensity, studying these effects and processes in depth, defining sustainable varieties and finding ways to overcome temperature elevation becomes a worldwide concern. From the analysis conducted by the authors of the seasonal maximum and minimum temperatures measured by the Israel Meteorological Service over the last 20 years in Central Israel (ARO, Israel; 31°59′32.6″ N 34°49′03.8″ E), an alarmingly steady trend of rising temperatures was derived. When mean temperature elevation was calculated for the different seasons (Dec–Jan defined as winter, Mar–Apr defined as spring, and Jul–Aug defined as summer), a linear trend of an almost 2 °C increase was demonstrated for summer, and linear trends of a 0.5 °C increase for winter and spring were validated, over the last 20 years (**Figure 1**). Here, we will review each part of the developmental process of the olive fruit, in view of the biochemical processes behind them, and assess the effect of elevated temperatures on olive flowering, fruit development, oil accumulation, and oil quality.

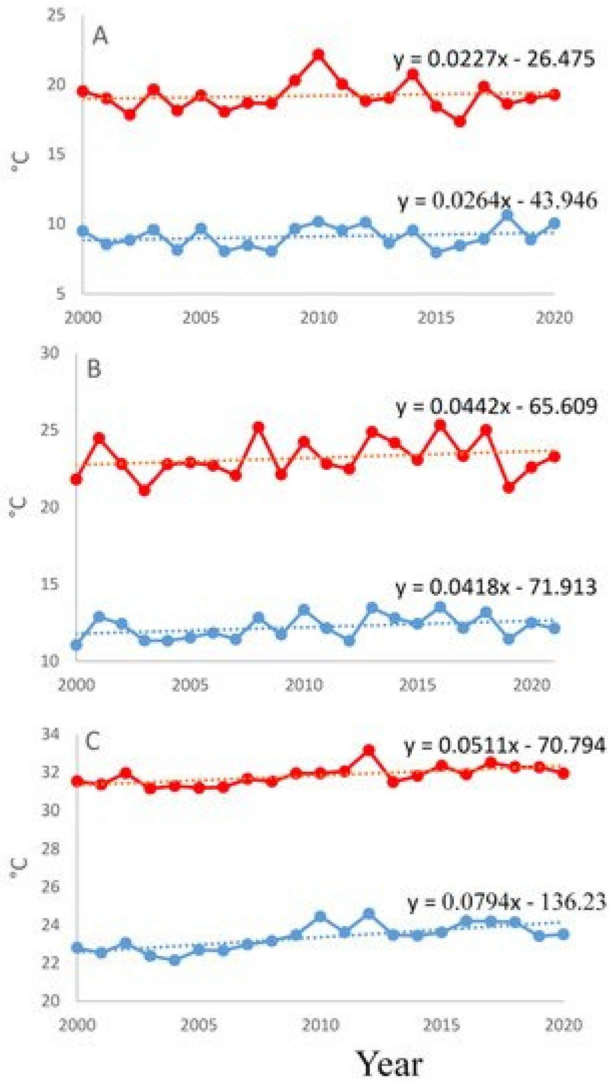

Figure 1. Seasonal average maximum/minimum temperatures measured over the last 2 decades in Central Israel (Bet Dagan; 31°59′32.6″ N 34°49′03.8″ E). Data were collected by the Israel Meteorological Service. A trend of an increase by 0.5–2 °C was observed. Higher values reflect warmer summers, and lower values reflect warmer winters. (**A**) Winter (Dec–Jan); (**B**) spring (Mar–Apr); (**C**) summer (Jul–Aug). The red line presents the mean maximum temperatures; the blue line indicates the mean minimum temperatures; the dotted line shows a linear trend.

2. Olive Oil Production under Elevated Temperatures

2.1. Oil Accumulation under Warmer Summers

Oil accumulation in olive fruits is known to begin in June and to last until mid-October. It then slows down during November–December [4][6]. The total period of drupe development from flowering until maturation lasts 18–20 weeks. During this period, the drupe passes through four developmental stages: 0–2 weeks after flowering (WAF) is characterised by ovary growth through cell division. From 2–6 WAF, the drupe grows by cell division. At 6–16 WAF, cells continue to expand, as lipids are stored in oil bodies in the mesocarpal cells. The last stage is 16–20 WAF, when epicarp colouration begins and the fruit peel begins to turn purple due to intense anthocyanin deposition in the cell vacuoles [7][8]. At harvest, oil droplets occupy about 80% of the cell volume [4][9][10].

Oil concentration shows an insignificant linear decrease of 1.1% per degree, as temperatures increased from 16 to 32 °C. Another increase of 7 °C has a permanent negative effect on oil concentration at final harvest, particularly when the exposure to high temperature occurs at the beginning of oil accumulation [11].

Elevated temperatures affect oil production [12]. This negative effect on oil production in plants is felt in different ways; for example, elevated temperatures reduce oil production in sunflower hybrids by 6% [13], but do not influence oil production in corn [14]. Olive oil concentrations, however, are even more complex, as the effect of higher temperatures is genotype-dependent [15]. The final oil concentrations of “Barnea”, “Picholine”, and “Coratina” do not change even when grown at almost 50 °C, while the oil concentrations of “Koroneiki” and “Souri” decrease in average by 2% per degree of increased maximum daily temperature [4]. The oil concentration of the “Arauco” cultivar decreases by 1.1% per degree of increased temperature [11]. “Coratina” and “Arbequina” trees reduce oil concentration by 5% on average as a response to warmer environments. This was demonstrated for other cultivars as well [16].

García-Inza et al. [17] showed that besides the mean maximum temperature, other heat temperature parameters should be also evaluated, i.e., mean minimum temperature and mean thermal amplitude. Thermal amplitude is the difference between minimal (night) temperatures and maximal (day) daily oscillation in temperatures. The thermal amplitude was found to have an inverse association with oil accumulation and a positive linear association with oil quality [18]. This means that as the gap between the maximum and minimum mean temperatures gets larger, oil yield reduces but oil quality is enhanced.

García-Inza et al. [11] found that high temperatures during oil accumulation negatively affect olive oil yield and quality in warm regions, particularly if high-temperature events occur early during the fruit development process, i.e., affecting cell division. However, our preliminary results suggested different findings. We found that fruit development is affected by elevated temperature regardless of the time of occurrence during this process, while oil accumulation and quality are most affect specifically when the high-temperature events occur after pit hardening (unpublished data). Fruit weights and oil accumulations in “Koroneiki”, “Coratina”, and “Picholine” are much lower when grown under high temperatures compared to those of the same cultuivars grown under milder temperatures. On the other hand, the “Barnea” cultivar exhibits greater tolerance for high temperatures; thus, final fruit weight and oil percentage are similar in olive trees grown under either high or moderate temperature conditions [19]. Final oil content is also cultivar-dependent, as “Barnea”, “Coratina”, and “Picholine” show no affect when exposed to high temperatures. The “Koroneiki” and “Souri” cultivars, under similar conditions, show drops in oil content by 15% and

8%, respectively. As for oil quality, the "Souri" cultivar shows higher tolerance to high temperatures than any of the other cultivars studied [4].

Nissin et al. [20] demonstrated the genetic mechanism controlling this genotype-dependent tolerance. The degree of induction of heat shock proteins as a response to high temperatures is cultivar-dependent. The heat-resistant "Barnea" cultivar shows a larger degree of induction than the heat-sensitive "Souri" variant. Moreover, different genes involved in olive oil biosynthesis are repressed when exposed to heat; the genes show cultivar-dependent expression patterns according to their heat tolerance characteristics [20]. Using these molecular observations, the identification or development of more heat-resistant cultivars maintaining high yield and quality of oil is critical for a future characterized by global warming.

2.2. Olive Oil Quality under Warmer Summers

Oil quality, which can be measured by high oleic acid ($C_{18:1}$) levels and/or low linoleic acid ($C_{18:2}$) levels, shows a positive correlation with oleic acid levels and negative association with linoleic acid levels. In other words, the high-temperature amplitude has a positive effect on oil quality [18]. No significant association with the mean maximum temperature was found, which is a crucial point in defining the relevant temperature correlated with those changes. The minimum temperature, on the other hand, has a strong negative effect on oil quality [18], suggesting that the attainment of high-quality oil requires somewhat elevated threshold temperatures. These results [18] suggest that recording spells of high temperatures alone does not reflect the complex conditions affecting fruit yield, oil content, and oil quality in olives. The minimum temperature and the thermal amplitude must also be considered.

Temperature is undoubtedly an important factor contributing to variations in oil quality, particularly the temperatures prevailing from the time of stone hardening until the beginning of fruit colour change, i.e., July till October [21]. Oil quality seems to be the parameter most acutely affected by high temperatures. Olive oil quality is determined mainly by the free acidity, expressed in % and defined by the relative concentration of the monounsaturated fatty acid named oleic acid ($C_{18:1}$), which has a clear impact on the quality of olive oil. The chemical composition of olive oil is composed mainly of oleic acid, which comprises up to 83% of the total, with residual amounts of palmitic acid ($C_{16:0}$; 7.5–20%), linoleic acid ($C_{18:2}$; 3.5−21%), stearic acid ($C_{18:0}$), and linolenic acid ($C_{18:3}$) [21][22]. The oleic acid concentration decreases by 0.7% per degree, as temperatures increase from 16 to 32 °C [18]. Commentary, the evaluation of oil quality is also based on several accepted physicochemical and sensory parameters, such as organoleptic quality and phenolic and volatile compounds, as defined by the International Olive Council (IOC) [23].

During summer, temperatures can reach up to 46 °C. Such high temperatures during oil accumulation can certainly decrease fruit size, oil yield, and oil quality. Oil quality defined by fatty acid composition (i.e., % oleic acid) and polyphenol levels is lower when grown in high temperatures for any of the studied cultivars. However, heat tolerance is genotype-dependent [4], where some cultivars' oil qualities are affected more than others. Thus, the oil qualities of the "Barnea" and "Picholine" cultivars are severely affected by high temperatures, while the "Souri" type is recognized as more heat-tolerant.

The chemical parameters used to determine olive oil quality are the total polyphenol profile and fatty acid composition. Polyphenol levels decrease during fruit development [24][25], positively corresponding with water restrictions [26][27]. Elevated temperatures lead to a dramatic decrease of up to 65% in the total polyphenol content of most analyzed cultivars [4].

As mentioned above, the second criteria of oil quality is the fatty acid composition, mainly the oleic acid content. In sunflower oil, for example, heat stress causes an increase in oleic acid content and a reduction of linoleic acid [13]. In olive, high temperatures cause a decrease in oleic acid concentration and increases of linoleic and palmitic acids [11][28]. The different mechanisms, leading to opposite outcomes, may be partly explained by the genes involved in the oil biosynthesis pathway as seen through their levels of expression [29]. The reaction begins in the cytosol and advances to the plastid and terminates at the endoplasmic reticulum. Tracking the expression pattern of genes involved in the oil biosynthesis in olive fruit reveals that oleic acid is produced when the fatty acid desaturases (FAD) are activated. In high-quality oil, oleic acid is produced through fatty acid desaturases, while FAD2 synthases remain inactive. However, when the tree is subjected to heat stress, FAD2 synthases are activated and linoleic acid is produced. As linoleic acid is synthesized from oleic acid, the level of oleic acid will decrease and levels of linoleic acid will rise [20].

The influence of temperatures during the growing season on fatty acid composition of 188 Italian cultivars was studied between 2001 and 2005. Significantly lower concentrations of oleic acid and higher palmitic and linoleic acids levels were found in the warmest year of the study (2003) compared to in the coolest year (2005) [21]. Standard levels of fatty acid composition in olive oil determined by the IOC state that olive oil must contain 55–83% oleic acid and 3.5–21% linoleic acid. The oils obtained from olives grown in extreme heat conditions contain up to 23% linoleic acid and only 52% oleic acid, neither of which meets the standards of the IOC [21].

Genotype variability was demonstrated in the present study. Out of the five cultivars analyzed, the “Souri” cultivar showed the smallest decrease in oleic acid (<4%) and the smallest increase in linoleic acid (1.5%) under elevated temperatures [4]. Taken with total polyphenol levels, this suggests that some cultivars may be more resistant to high temperature environments than the others. As global warming spreads, this information becomes extremely important.

The early harvesting of olives is an increasingly widespread trend in Mediterranean countries that aims to increase the quality of oils by using less mature fruits over the expenses of oil amounts. However, early harvesting in countries that have very warm autumns means harvesting and processing during higher temperatures, which may in turn affect the quality of oil [30][31][32]. The internal temperature of the fruits at the time of processing and the temperatures maintained during the milling and malaxation steps on olive oil quality should be considered.

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