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Olive trees in the world. Past and present with future perspectives

Oliveiras no mundo. Passado e presente com perspectivas futuras

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ABSTRACT

The cultivation of the olive tree is of great economic importance worldwide. For the 2022-2023 harvest, were produced around 3,010,000 Mg of olive oil and 2,955,500 Mg of table olives of selected varieties, managing to establish itself in approximately 56 countries with different environments. In most of the cultivated areas only monovarietals were used, but mixtures of varieties have been recommended, which act as pollinators, avoiding reproduction problems. Furthermore, global warming also affects production efficiency and the quality of derived products. The olive grove underwent important changes due to genetic improvement. However, despite modern molecular tools, most of the work continues to be based on agronomic classical methods such as crossing and selection in progeny, delaying the development of new varieties. Models with high resolution climate projections are being used, allowing predicting the future evolution of the olive tree. Unfortunately, Brazil produces only 0.2% of its internal consumption and therefore has become the world's second largest importer after the United States to cover the growing demand. Based on this information, this review aims to discuss the adjustments in olive growing, which has been gaining more and more areas dedicated to its cultivation in Brazil.

KEYWORDS: olive tree cultivation; olive oil production; *Olea europaea* L; climate change**.**

RESUMO

O cultivo da oliveira é de grande importância econômica mundial. Para a safra de 2022-2023 produziu-se cerca de 3.010.000 t de azeite e 2.955.500 t de azeitonas de mesa de variedades selecionadas, conseguindo se estabelecer em aproximadamente 56 países com ambientes diversos. Na maioria das zonas cultivadas foram utilizados apenas monovarietais, porém tem sido recomendadas misturas de variedades, que atuem como polinizadores, evitando problemas de reprodução. Além disso, o aquecimento global também afeta a eficiência da produção e a qualidade dos produtos derivados. O olival sofreu alterações importantes devido ao melhoramento genético. No entanto, apesar das ferramentas moleculares modernas, a maior parte do trabalho continua a se basear em métodos agronômicos clássicos, como cruzamento e seleção na progênie, retardando o desenvolvimento de novas variedades. Modelos com projeções climáticas de alta resolução está sendo utilizados, permitindo prever a evolução futura da oliveira. Infelizmente, o Brasil produz apenas 0,2% do seu consumo interno e, portanto, tornou-se o segundo maior importador mundial depois dos Estados Unidos para cobrir a crescente demanda. Com base nessas informações, esta revisão tem como objetivo discutir os ajustes da olivicultura, que vem ganhando cada vez mais áreas dedicadas ao seu cultivo no Brasil.

PALAVRAS-CHAVE: cultivo de oliveiras; produção de azeite; *Olea europaea* L; mudanças climáticas.

INTRODUCTION

In the last 20 years, the development of olive growing has taken presence due to the so famous and healthy Mediterranean diet, especially on the quality and nutritional and antioxidant characteristics attributed to it (SCHWINGSHACKL & HOFFMANN 2014). Apparently, this ancient and iconic tree has become a source of profitable and constant investment (RUIZ 2016, RUIZ et al. 2018, GULLÓN et al. 2020, COI 2021a).

This boom has led to a diversification of cultivars, increasingly better adapted to environmental conditions both throughout the Mediterranean basin as and in some countries that are outside their place of origin, towards the intertropical fringes of both the northern and southern hemispheres (ALFIERI et al. 2019). In almost all these areas, olive cultivation has been carried out in a traditional way, producing an amount of oil well below world demand (COI 2021a).

Despite the fact that the new olive plantations are being cultivated under high-density systems, there are still hectares that are susceptible to modernization. The demand in the international market and the commercialization have generated genetic improvement plans, allowing the modernization and intensification of the crop in order to maintain competitiveness, in turn focusing on improving the water management policy and increasing the availability of hydric resources (COUTINHO et al. 2009, MOUSAVI et al. 2019, PALOMO-RÍOS et al. 2021, SKODRA et al. 2021).

Brazil, despite of the policy intention to grow and become an olive tree-producing country, establishing high-quality standards and international recognition, with a focus on promoting its planting; for the year 2021, unfortunately continued to position itself as the second largest world importer of oil olive, with a national production that barely reached 0.2% of its internal consumption (COI 2021a, 2021b). For this reason, a bibliographic review was carried out to contribute to updating the knowledge of olive cultivation in the South of Brazil, taking a look at the past, contextualizing the present, and doing prospects to face demand growing and the global problems that climate change can affect it.

DEVELOPMENT

Brief history of the origin and domestication of the olive tree

The commercialization of the olive tree dates back to the 12th century BC, coinciding with the expansion of civilizations that inhabited the Mediterranean basin (MARTÍN-PUERTAS et al. 2009, KANIEWSKI et al. 2012, ZOHARY et al. 2012, OTEROS 2014a, OTEROS et al. 2014b, INFANTE-AMATE et al. 2016, BESNARD et al. 2018, COI, 2021a). However, the origin and propagation channels of the species are not entirely clear (LOUKAS & KRIMBAS 1983, BESNARD et al. 2013, GUERRERO-MALDONADO et al. 2016, LANGGUT et al. 2019, FRAGA et al. 2021).

According to the archaeological data, the wild olive tree could have originated in Asia Minor, which is extremely abundant and grows in dense forests (COI 2021a), spreading from Syria to Greece via Anatolia (DE CANDOLLE & LOUIS 1982). A second hypothesis indicates an origin in the Dead Sea (ZOHARY & SPIEGEL-ROY 1975, CAVAGNARO et al. 2001, FENDRI 2011, LANGGUT et al. 2019) based on the selection of *Olea europaea* var. *sylvestris* Brot., from the region of Iran, Mesopotamia, Palestine and the Syrian coastal zone in the Middle East (DRAGO 2015). Cultivation developed from the southern Caucasus to the Iranian plateau and the Mediterranean coasts of Syria and Palestine. From there, it managed to spread to Greece, Italy, France and Spain. In addition to spreading to the south of Egypt, Tunisia and Morocco (ZOHARY & SPIEGEL-ROY 1975, ÖZKAYA et al. 2004, RALLO 2005, NEWTON et al. 2006, FENDRI 2011, GARCÍA 2012, TERAMOTO et al. 2010, DRAGO 2015, ADAKALIC & LAZOVIC 2018, LANGGUT et al. 2019, COI 2021a).

Whatever the hypothesis of origin, the natural distribution of the olive tree is restricted in the Mediterranean basin, as these trees with little genetic variability are adapted to habitats with hot, dry summers and mild winters (FENDRI 2011, WREGE et al. 2015), with little contrast between seasons due to the regulating action of the climate, exerted by the Mediterranean Sea on land. Thus, the plants have depended on human action in spreading the cultivation surface (OTEROS et al. 2013, 2014b).

The Arabs mixed their cultivars with those from the south of Spain, influencing the spread of cultivation. Such was their influence that the name of the fruit of the olive tree and the oil in various languages derived from Latin has Arabic roots *az-zayt* or *zaitum*, translated from the Hebrew *Zait,* which means oil (MARCH & RIOS 1989, RAE 2023). The olive tree occupied a large stretch of Andalucía and spread to the Mediterranean coastal area of the Iberian Peninsula, including Portugal, increasing the export of oil by sea (GOMES 1979, BARRANCO & RALLO 1984, COI 2021a, 2021b).

The cultivation was transported by Spanish missionaries to the Antilles in the American continent in 1520, taking them to the Caribbean and the central region of Mexico (GOMES 1979, SOLERI et al. 2010, WREGE et al. 2015). Later, they were spread throughout North America (California) and South America (Peru, Chile, Argentina, Uruguay, and Brazil), where they had better production (WREGE et al. 2015). Currently, the olive sector continues to spread outside the Mediterranean, colonizing places like as southern Africa, Australia, China, Japan and Hawaii (CIVANTOS 2004, MUZZALUPO 2012, SANTOS 2016, CHIAPPETTA et al. 2017).

In Colombia, attempts were made to plant olive trees in the Villa de Leiva and Boyacá region, but generated poor results (TAGUAS 2009, GARCÍA 2012). In Chile, Peru, and Argentina, the introduction of olive trees was made between the years 1550-1560, but due to the development of crops, King Carlos III ordered cutting them from Alto Peru to the Rio de la Plata, fearing that the prosperity and its commercialization would affect Spain's monopoly in the world (HIDALGO 1993).

In Argentina, commercial olive plantations date back to the 1940s, but the activity began to strengthen in the late 1990s, mainly driven by industrial promotion and rising international prices (GONZÁLEZ & CEBRINO 2016). In Uruguay, the crop was introduced from Argentina, having a better development as of 2002, the year in which the National Institute of Agricultural Research (INIA) began to evaluate cultivars and oil quality, creating the ASOLUR (GONZÁLEZ & CEBRINO 2016).

In Brazil, the olive tree was introduced in the 15th and 16th centuries (GOBBATO 1945, OLIVEIRA & BASTOS 2011), in the states of São Paulo, Paraná, Santa Catarina, Rio Grande do Sul, Minas Gerais, Espirito Santo and Rio of Janeiro. However, most olive groves were cut in royal order, as Portugal, with the same decision as Spain, did not want its products to suffer competition in Brazil (GOMES 1979).

Economic importance of olive trees

Olive growing is an activity of great economic, food, energy and political importance, which is why it has become a key trade crop in the Mediterranean (RUIZ 2016, RUIZ et al. 2018, GULLÓN et al. 2020). Generally, the olive tree is cultivated alone, but sometimes it is associated with cereals, vineyards, sunflowers or other crops that make it possible to compensate for the variations in the costs or alternating production. In other words, after a year of an abundant harvest of olives, there is one or two years in which the harvest is small, and this phenomenon necessarily occurs every two years (FRAGA et al. 2021).

Every year, the area devoted to the cultivation of olive trees grows by approximately 150,000 hectares, and there are currently approximately 56 oil-producing countries where there are around1.5 billion olive trees planted on 11 million hectares, producing in the 2022-2023 harvest, approximately 3,010,000 Mg of oil and 2,955,500 Mg for table olives (COI 2021a, 2021b, COI 2023). However, according to calculations by the International Olive Council (COI), the global deficit between production and consumption can exceed approximately 300,000 Mg (MANZANARES et al. 2020, GULLÓN et al. 2020, COI 2021a, 2021b).

For the 2022-2023 harvest, the world's leading olive oil producer remains Spain (COI 2023), whose average yield of 2.46 $Mg.ha^{-1}$ of collected fruits generated a yield of 1,389,000 Mg of olive oil (46.14% of world production), surpassing its closest competitors by more than four times. Greece had a productivity of 2.14 $Mg.ha^{-1}$ (275,000 Mg. of oil), Italy 2.09 $Mg.ha^{-1}$ (274,000 Mg of oil) and Portugal 0.67 Mg ha^{-1} (100,000 Mg of oil).

According to the most up-to-date statistics, for the 2019-2020 harvest, the world's largest producer of table olives was Egypt, with an average yield of 7.1 $Mg.ha^{-1}$, producing a total of 690,000 Mg of collected fruits (23.35 % of world production), followed by Spain 3.38 $Mg.ha^{-1}$ (500,000 t of fruits) and Turkey 1.86 $Mg.ha^{-1}$ (414,000 Mg of fruits) (COI 2021a, 2021b).

Considering the American continent, in Peru, the olive tree has been used to produce table olives, with a planting area of 23,168 hectares (SENAMHI 2020). In the 2019 harvest, production was 45,000 Mg (with an average yield of 1.94 $Mg.ha^{-1}$) and a fruit export that reaches 22,779 Mg (SENAMHI 2019, COI 2021a, COI 2023) to countries like Brazil, States United, Venezuela, Chile, Italy and Israel (GUTIÉRREZ 2007, GARCÍA 2012). Chile has experienced remarkable development in recent years, with the incorporation of areas for planting and technical production (DONOSO 2006), producing in 2021, approximately 20,000 Mg of olive oil and 13,000 Mg of table olives (INFAOLIVA 2019, COI 2021a, 2021b), with an average olive productivity of 4.65 $Mg.ha^{-1}$.

In Argentina, the cultivated area is approximately 78,050 hectares, of which 70% correspond to cultivars for oil extraction (GONZÁLEZ & CEBRINO 2016), producing for the 2020-2021 harvest, approximately 27,000 Mg of oil, with an average productivity of olives at 6.04 Mg.ha^{-1}. The production of table olives was 100,000 Mg, with an average productivity of 4.27 Mg.ha^{-1} (COI 2023). In Uruguay, the cultivation of olive trees occupies an area of 9,100 hectares, obtaining, for the year 2021, close to 500 Mg of olive oil, an amount that is much smaller than that of the 2019-2020 crop year (3000 Mg). The average productivity in the country is 1.05 Mg.ha^{-1} (ACKERMANN & GORGA 2019, COI 2021a, 2021b). The differentiated quality of olives from Argentina and Uruguay, the careful choice of cultivars and the search for new cultivars adapted to local conditions, made these countries become members of the International Olive Council (COI), being the only representatives from South America, fulfilling the organoleptic/sensory and chemical requirements established by the governing institution of the international production of olive oil (COI 2021a, 2021b).

In Brazil, approximately 400 producers have cultivated about 6,000 hectares with 1,664 million olive trees, of which 3,464 are located in Rio Grande do Sul (RS), belonging to 145 producers distributed in 56 municipalities (SEAPDR 2020). It has been calculated that Brazil has a production capacity of 6,500 Mg of olive oil, which represents lowest than 0.2% of national internal consumption, the exploitation area being limited due to the reduced areas with suitable local climatic conditions for its development (WREGE et al. 2015). The average productivity of olives in the country is 0.35 Mg.ha^{-1}, and in RS it is 0.41 Mg.ha^{-1}. The high consumption reported by the International Olive Council (COI) for the year 2021 (104,000 Mg of olive oil), places the country, after the US, as the second-world importer of olive oil (8%), with a rate of projected growth variation of 20.6%. The efforts and investments made in the search for planted areas still do not present commercial plantations of significant economic impact to supply the growing domestic demand (COI 2021a, 2021b).

The import of olive oil and olives in Brazil involves a cost of approximately 200 million reais per year, and these products come from Argentina, Peru, Chile, Spain, and Portugal (MORA et al. 2007). The volume of imports of olive oil and olives in the country has grown in recent years, increasing 476% in olive oil and 317% in the volume of imports of table olives in the last 5 years (SILVA 2011, SILVA & REBOITA 2014), due to the benefits of their consumption and more affordable prices.

Productivity problems in olive trees

In the Mediterranean basin, hundreds of olive cultivars are selected for their adaptation to various microclimates and soil types. However, most of the cultivated area only has monovarietal (BARRANCO 1995, ESPAÑA 2021), so some authors recommend mixed with other cultivars, which act as pollinators. The use of several cultivars in an area ensures a good set of viable fruits, thus avoiding the formation of parthenocarpic fruits "shotberries", that is, prone to abscission and without commercial value, this being a consequence of self-fertilized plants (CUEVAS & PINILLOS 2006).

Due to the occurrence of self-incompatibility in olive germplasm, the cultivars have a degree of heterozygosity with high genetic variability, doing the potential for improvement relevant (FABBRI et al. 2009). Self-compatibility evaluations in different cultivars have shown variable results in relation to their productivity, when different years and places are compared (CUEVAS & PINILLOS 2006, LAVEE et al. 1996). These results are even more uncertain when adding the fact that there are considerable differences within the same cultivar, with the degree of self-incompatibility being highly variable (LAVEE et al. 1996, WU-BIAO et al. 2002). This allowed proposing a "pseudocompatibility" mechanism, influenced by environmental conditions (ALAGNA et al. 2019).

The degree of self-incompatibility in the olive tree is debatable. In Italy, many cultivars are considered self-incompatible (ANTOGNOZZI & STANDARDI 1978, BANDINO & DETTORI 2003). However, at least a third of the same cultivars in Spain are considered partially self-compatible (CUEVAS et al. 2001; CUEVAS & POLITO 2004). Thus, attempts to develop new cultivars have been sporadic and complicated (ARSEL & CIRIK 1994, LAVEE et al. 1996).

Studies on the identification of compatible cultivars have given contradictory results, probably due to the different environmental conditions of the study or, sometimes, to confusion in same cultivar identity (MEKURIA et al. 1999, ÖZKAYA et al. 2004, ALBA et al. 2009), as there are more than 3,000 synonyms and homonyms that still need to be reclassified (BARTOLINI et al. 1988, ÖZKAYA et al. 2004, PEREIRA et al. 2015, RALLO 2005, ADAKALIC & LAZOVIC 2018). Some cultivars, such as Moraiolo, Arbequina or Manzanilla, have been contradictorily identified as self-compatible (SIBBETT et al. 1992, COI 2000, COUTINHO et al. 2009) or self-incompatible (SÁNCHEZ-ESTRADA & CUEVAS 2018). Furthermore, self-compatibility and response to pollen donors may vary according to the climatic variability of the year's seasons (LAVEE et al. 1996). In turn, the high variation in floral expression between years (LAVEE et al. 1996) and between the cultivars (SEIFI 2008) could have to the nutritional requirements (COI 2007) and the biennial behavior (LAVEE et al. 1996). The fact that the olive tree is self-incompatible marks its dependence on cross-pollination. Under these conditions, several authors propose artificial pollination as a temporary or definitive alternative, which can be adapted for large or super-intensive plantations (TOUS et al. 2003). For this, efficient and economical methods must still be developed for collecting large amounts of pollen, maintenance, storage at low temperatures, and guaranteeing viability over time (RUIZ et al. 2018). In addition to profiling, the identification of pollen donor plants with the help of molecular techniques (DE LA ROSA et al. 2002).

In addition to genetic conditions on reproduction that cause self-incompatibility, the olive tree faces environmental factors such as temperature (FABBRI & BENELLI 2000) that can affect the induction and differentiation of flower buds, pollen germination, drastically influencing productivity and generating severe impacts on economic (AYERZA & COATES 2004, DANTAS et al. 2005, RODRIGUEZ-ROJAS et al. 2015).

In addition to reproductive problems, global warming as a consequence of climate change, has affected the production efficiency and quality of products derived from olive trees. This impact is due to the fact that the size and filling of the fruit differ not only from its genetics but are also influenced by the region, the climate, and the geographical position, as well as the agricultural management, so it depends on a great extent of anthropogenic activities (OZTURK et al. 2021). The olive tree requires areas with low rainfall and winter cold conditions. Unfortunately, in Brazil, these two conditions hardly co-occur in the same place. There have been several research efforts in the states of Rio Grande do Sul, Santa Catarina, Minas Gerais, and in the semi-arid region to organize edaphic-agroclimatic zones related to the ecological and production needs of the olive tree (WREGE et al. 2011, 2015). Generally, cold areas, such as the mountainous regions of Rio Grande do Sul and Santa Catarina, have high relative humidity and precipitation rates, presenting problems during the flowering season, when pollen grains become heavy and unviable due to turgor, and therefore, the formation of fruits does not occur (WREGE et al. 2015). The areas with the lowest precipitation rate are warmer zones, such as the semi-arid region of northeastern Brazil, where precipitation is around 600mm. However, the region does not meet the cold hours accumulated during the winter necessary for the induction of buds and leaf/flower differentiation. Apparently, irrigation, generally combined with more modern techniques and intensive production methods, has been recommended (BARRANCO & RALLO 2000), an issue that would be very beneficial for Brazil, which already knows the existing local climatic conditions.

In recent decades, the olive grove has undergone important technological changes, highlighting the increase in plant density associated with an improvement in the mechanization of harvesting. To reduce production costs, it went from intensive systems of 200 and 300 trees/ha and collection by trunk vibrator to a super-intensive system, with densities above 1,500 trees/ha, from which there is continuous harvesting through machines mounted above trees (TOUS et al. 2003). This type of superintensive cultivation system causes that, from the sixth or seventh year onwards, production decreases due to the lack of lighting and aeration inside the trees, causing a higher incidence of pests and diseases, in addition to making them more susceptible to abiotic stress (COI 2007).

Olive tree genetic improvement

The olive tree is a complex case study in the domestication of fruit trees (SKODRA et al. 2021). Most of the genetic improvement works in olive trees have been based on classical methods that include crossing and selection in the progeny, slow development due to the plants' long juvenile period (LAVEE et al. 1996).

Many of the plant breeding programs are located in Spain, Italy, Tunisia, and Israel, generating successful varieties in their erect and narrow growth, earliness, high production, and fat yield (LAVEE et al. 1996, MOUSAVI et al. 2019, PALOMO-RÍOS et al. 2021, SKODRA et al. 2021). However, despite the large number of programs, the number of varieties obtained is small compared to other fruit trees (DE LA ROSA et al. 2007), in addition to presenting great uncertainty with the large number of synonyms and homonyms still scattered around the world (COI 2021a, 2021b).

A useful tool in the genetic improvement of the olive tree was the creation of the World Bank of Olive Germplasm located in Córdoba, which is of great importance for having many varieties exhaustively maintained and evaluated (CABALLERO & DEL RÍO 2005). In addition to generating analysis to reduce the time necessary to produce new resistant varieties (FENDRI et al. 2010). There are breeding programs in Australia to obtain varieties adapted to local environmental conditions from feral material (SEGDLEY 2000).

In spite of the large number of resources needed to pursue genetic improvement, the Olive productors countries have promoted clonal selection programs with often encouraging results. However, the main difficulty is the relatively scarce knowledge of the hereditary behavior of the most important bioagronomic traits, the high heterozygosity of the species and its high degree of polymorphism (MOUSAVI et al. 2019, CHACÓN-ORTIZ et al. 2022). This, in turn, means that the minimum time for releasing a new cultivar could be 20 years or more (FABBRI et al. 2009). The consequence of all these problems is that the olive has not received attention in recent decades to other fruit crops as concerns genetic improvement using cross-breeding approaches. This fact is clearly evidenced by the very limited number of new cultivars and rootstocks that have been released in the last 30 years (COI 2021a).

During the last 20 years, several genetic tools have improved the understanding of the olive tree's domestication, propagation and diversification processes (SKODRA et al. 2021). Since it has been difficult to decipher the adaptive evolutionary processes involved in the domestication of the olive tree (PONTI et al. 2014).

Future prospects for climate change

Species distribution models, united with high-resolution climate projections, have permitted to predict the future evolution of the most common olive varieties (ALFIERI et al. 2019, ARENAS-CASTRO et al. 2020, RODRIGO-COMINO et al. 2021). Warmer winters and increased drought have been estimated to lead to reduced rainfall and loss of soil moisture, limiting the number of areas available for commercially relevant cultivars that have been traditionally developed. This is thus forcing producers to replace traditional varieties by better adapted to intensive or super-intensive productivity (SANTOS et al. 2019, ARENAS-CASTRO et al. 2020). Still, some detractors believe that olive trees are extremely resistant and unlikely to undergo drastic changes (ALFIERI et al. 2019, FRAGA et al. 2021, COI 2021), despite the harsh climate changes projected in the future and their implications for agriculture (BRANCA et al. 2021).

Climate projections in Brazil indicate considerable changes related to increases in air temperature (SILVA et al. 2019, MARTINS et al. 2020), affecting agriculture and altering development rates and phenology in the olive tree. This can largely be due to the low availability and accumulation of cold hours (FLORÊNCIO et al. 2019, FRAGA et al. 2019, MARTINS et al. 2020), directly impacting reproduction and fruiting.

CONCLUSION

Regardless of the fluctuations in olive production, the growing market demand leads to intensive or super-intensive industrial planting. Consequently, this entails an imbalance of ecosystems and probably a loss of identity and cultural heritage. However, it must find a way to make the business profitable and, above all, to achieve a balanced level of long-term income, a complicated issue in Brazil, whose productivity is linked to the climate, the fertility of the land, and the productive alternation, in addition to demonstrate its local quality in a still incipient olive market and culture.

A study solution for Brazil should involve searching, with the help of bioinformatics tools, which genes are differential expressed in the cultivars best adapted under local climate conditions, if compared with the same cultivars in other localities, including origin locality, which could be the basis of a differential search pattern for new, more efficient cultivars developed in the country.

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