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Evaluation of the fruit characteristics and quality of five olive cultivars grown in different orchards in Longnan, China

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Abstract

The quality of virgin olive oil is closely related to the quality of olive fruits. The primary aim of the present work was to assess the olive fruit quality of five major olive cultivars (Frantoio, Leccino, Ezhi-8, Picholine, and Coratina) cultivated in Longnan, which is an emerging region for olive plantation in China. Measurement and gravimetric methods were used to study the biological properties of olive fruits, while the biochemical constituents were analysed by colorimetry. The results of morphological and biochemical analyses showed that the olive fruits of the five cultivars had excellent quality with relatively high oil contents and bioactive components (flavonoids and phenolic compounds). The oil contents in freeze-dried sarcocarp ranged from 49.25 to 71.11%. The shape parameters, biological characteristics, and bioactive components of olive fruits varied with genetic characteristics of cultivar, ripeness, and physicochemical factors of soil. There was a certain negative correlation between total carbohydrate and oil content in sarcocarp, as well as between total polyphenol content and polyphenol oxidase activity. The principal component analysis (PCA) results showed that the evaluation indexes of the olive fruit quality mainly include the biological characteristic parameters (fruit size and weight, sarcocarp, and oil content) and the contents of bioactive components (saccharides, polyphenols, and flavonoids). Furthermore, the soil nutrients and physicochemical properties also affected the fruit quality. Our findings suggest that the olive fruit produced in Longnan has excellent production performance, and the fruit quality is closely correlated with the genotype of olive cultivar, growing environment, and soil conditions.

Abbreviations

SHZ: Shanghouzi; BHQ: Baiheqiao; ZZP: Zazipo; DJB: Dongjiaba; LTC: Litingcun; MCS: moisture content of soil; TNC: total nitrogen content; TOC: total organics content; RAP: rapid available phosphorus; WSF: weight of single fruit; FLD: fruit longitudinal diameter; FTD: fruit transverse diameter; FSI: fruit shape index; SCF: sarcocarp content of fruit; MCF: moisture content of fruit; OOC: olive oil content; TCC: total carbohydrates content; TFC: total flavonoids content; TPC: total polyphenols content; TSC: total saponins content; PPO: polyphenols oxidase; PCA: principal component analysis.

Introduction

Olive oil is becoming increasingly important as a food source due to its beneficial effects on human health. Some of these effects are related to the phenolic compounds, high amounts of oleic acid, tocopherols and phytosterols present in olive oil (Kalua *et al.,* 2007). Olive trees have made Spain, Italy, Tunisia, and Greece as the world's most important producers of olive oil since olive plantation springs up easily around the Mediterranean countries. Health features of polyphenolic antioxidant plant components and their probable use as natural food additives have been subjected to high scientific and commercial interests (Omar, 2010; Lafka *et al.,* 2013). Again, due to its excellent nutritional values, flavour, and taste, olive cultivation has been recently brought to regions far from the Mediterranean basin, particularly in South and North America, Oceania, and Asia (Longobardi *et al.,* 2012).

Since the cultivation of olive in the 1960s, China's olive planting and processing industry has been steadily developing. Yunnan, Sichuan, and Gansu provinces have established the olive planting and processing industry in response to the demand for this new source of vegetable oil (Wang *et al.,* 2019). With the expanding of olive planting in these three provinces,

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the olive industry there has thrived to a certain degree. For example, Longnan city in Gansu province has become one of the biggest areas for olive cultivation and processing in China. Moreover, after 60 years of development, several olive cultivars were proved suitable for planting in Longnan, including Frantoio, Leccino, Ezhi-8, Picholine, and Coratina (Wang *et al.,* 2019).

Olive oil is a kind of edible vegetable oil directly extracted from fresh olive fruit by low temperature physical treatment, and its quality is significantly impacted by olive cultivar, growing region, and agronomic condition of plantation (Cerretaini *et al.,* 2006; Temime *et al.,* 2006; Usanmaz *et al.,* 2019). Many studies have been carried out on the quality of olives and olive oil in Mediterranean countries (Conde *et al.,* 2008; Kotsiou and Tasioula-Margari, 2016; Wani *et al.,* 2018). Moreover, the floral biology of an olive cultivar (Leccino) from Italy was also investigated (Bartolini and Viti, 2018). Nevertheless, few researches have been conducted on emerging olive producers such as China (Xiang *et al.,* 2017). Longnan City in Gansu Province is the biggest planting and processing area of olive in China; so, it was marked into the world olive distribution map by the International Olive Oil Council in 1998. However, comparing with other olive origin countries, China still lacks an in-depth investigation on the introduction and cultivation of cultivars, culture physiology, and nutritional and fruit quality. Moreover, most researches have reported the chemical composition and quality evaluation of olive oil from Mediterranean region, but little attention has been paid to the characteristics and quality of olive fruit.

In the present work, five olive cultivars (Frantoio, Leccino, Ezhi-8, Picholine, and Coratina), which are mainly cultivated in Longnan region, were selected for analyses. The fruit quality of the five olive cultivars from different orchards was compared and estimated from exterior quality, biological characteristics, biochemical compositions, and bioactive components. Furthermore, principal component analysis (PCA) was adopted to screen the main factors determining the quality of olive fruit. It is hoped that the findings of the present work can help to better understand the quality of olives growing in Longnan.

Materials and methods

Chemicals

All the analytical-grade solvents and reagents were purchased from Sinopharma Chemical Reagent Co. Ltd. (Shanghai, China) and Shanghai Zhongqin Chemical Reagent Co. Ltd. (Shanghai, China).

Plant materials and sampling places

On October 25th, 2014, five olive cultivars (Frantoio, Leccino, Ezhi-8, Picholine, and Coratina), which grow in Wudu District, Longnan City (Gansu Province in China), were sampled by handpicking at harvest time. The administrative and geographical locations of the five sampling orchards were as follows; Tanchang County: Shanghouzi (SHZ) orchard in Shawan Town (33°39’24’’N, 106 104°31’45’’E); Wudu District: Baiheqiao (BHQ) orchard in Gongjiao Town (33°34’18’’N, 104°38’11’’E); Zazipo (ZZP) orchard in Liangshui Town (33°26’47’’N, 104°46’38’’E); Dongjiaba (DJB) orchard in Jugan Town (33°16’3’’N, 105°6’35’’E); and Litingcun (LTC) orchard in Waina Town (33°8’38’’N, 104°59’32’’E). In each orchard, three to five olive trees of the same cultivar were selected, and about 2 kg of fruit samples were randomly picked from different canopies and heights. The olive samples were immediately transported to the laboratory within 12 h, and stored in refrigerator at 4°C.

Analysis of soil physical and chemical parameters

The physicochemical parameters of the soil samples (moisture content of soil (MCS), pH, total nitrogen content (TNC), total organic content (TOC), rapid available phosphorus (RAP), Mg^{2+}, K^{+}, and Ca^{2+}) were measured by the methods recommended by Liu and Ma (2012).

Determination of biological characteristics of olive fruit

Fifty olive fruits (about 2 kg) were randomly selected from each cultivar, and the weight of single fruit (WSF, g) was determined by gravimetric method. The olive fruit longitudinal diameter (FLD, cm) and fruit transverse diameter (FTD, cm) were measured with a Vernier calliper. The ratio of the FLD/FTD of olive fruit represented the fruit shape index (FSI). The kernel (i.e., seed) was also weighed after the sarcocarp (i.e., flesh / pulp) was completely removed. The sarcocarp content of fruit (SCF) was expressed as fresh weight percentage (%).

Sample preparation and analytical methods
Determination of moisture content of fruit (MCF)

About 10 g of homogenised fresh whole olive fruit samples were weighed and dried at 80°C, and then at 105°C to constant weight. The MCF was calculated from the weight difference before and after drying.

Extraction and determination of olive oil content (OOC)

The fresh olive fruits (about 200 g) were rapidly frozen with liquid nitrogen for three times, homogenised with a mill, and carefully removed from kernels. Finally, the powdered sarcocarp samples were dried in a

lyophiliser (Zhejiang, China). Crude olive oil was extracted from 20 g of freeze-dried sarcocarp sample. Then, it was extracted three times with 100 mL of *n*-hexane in a glass flask. The crude olive oil in *n*-hexane was collected and weighed after removing the solvent in a rotary evaporator and drying. The OOC was expressed based on dry sarcocarp weight (%).

Extraction and determination of active ingredients in sarcocarp

Ten grams of freeze-dried and defatted sarcocarp sample was weighed and extracted in 100 mL of distilled water in a flask for 2 h at 80°C. Then, the extract was centrifuged at 5,000 *g* for 10 min, and the supernatant was collected. The precipitate was extracted again under the same conditions mentioned. All the supernatant was mixed and made at a constant volume to 200 mL. The extract was then used for the determination of bioactive ingredients after proper dilution.

Total carbohydrates content (TCC) was detected by the method of anthrone-sulphuric acid colourimetry at 620 nm (Model V-5000, Shanghai, China). Glucose was recommended as the standard for calculating the equivalent content of total carbohydrates (Roe, 1955). Total flavonoid content (TFC) was determined by sodium nitrite-aluminium nitrate colorimetric method at 510 nm. The TFC was expressed as the absolute concentration of rutin (Zhishen *et al.,* 1999). Total polyphenol content (TPC) was determined by adding 2.5 mL of Folin-Ciocalteu reagent and 2 mL of sodium carbonate (7.5%) to 0.5 mL of the liquid sample, and 2 h later it was measured at an absorbance of 760 nm by the spectrophotometer. The content of total polyphenols was expressed as the absolute concentration of gallic acid (Singleton and Rossi, 1965; Alrahmany and Tsopmo, 2012). The modified colorimetric assay of perchloric acid-vanillin-glacial acetic acid was applied to determine the total saponin concentration (TSC). The absorbance at 546 nm was measured, and the concentration of total saponins was expressed as the oleanolic acid content (Hiai *et al.,* 1976; Ncube *et al.,* 2011).

Extraction and assay of polyphenols oxidase (PPO)

Ten grams of freeze-dried olive sarcocarp sample (added with 4 g of polyvinylpyrrolidone, PVP) was extracted under pH 7.0 for 1 h with 100 mL of 50 mmol/L phosphate buffer at 0 - 4°C. Then the extract was centrifuged at 5,000 *g* at 4°C for 10 min, after which the supernatant was collected. The precipitate was extracted again under similar conditions. The two supernatants were pooled and made at a constant volume of 200 mL. The extract was used as the sample to assay the PPO activity in olive sarcocarp. Catechol (0.1 mol/L) was used as PPO substrate, and the absorbance rising at 410 nm was recorded every 30 s. One unit of PPO was defined as 0.01 rising at 410 nm per min. The results were expressed as U/(g·min) ($n = 3$) (Ortega-García and Peragón, 2009).

Statistical analysis

Basic statistical analyses of data were performed with MS Excel 2010. SPSS Statistics 17.0 Software was used for testing the significant difference at $p < 0.05$ level, correlation analysis, and principal component analysis (PCA). All the results were expressed as means ± SD, and the significant difference was marked with different lowercase/uppercase letters.

Results and discussion

Physicochemical properties of soil samples

The soil pH and MCS differences of five orchards ranged from 8.04 to 8.68, and 8.82 to 12.57%, respectively. The pH values of the soil from the five orchards were higher than 8.0, indicating that the soil was alkaline. The MCS in different orchards showed a certain difference; SHZ was the lowest (8.82%), and DJB was the highest (12.57%). TNC and TOC in the five orchards showed that there were no significant differences among SHZ, BHQ, DJB, and LTC, except for ZZP. Efficient phosphorus contents in the five places ranged from 18.92 mg/kg (BHQ) to 79.18 mg/kg (ZZP). The contents of K^+ in the five orchards had no significant difference ($p > 0.05$). The contents of Mg^{2+} and Ca^{2+} in other four orchards also showed no significant difference ($p > 0.05$), except for SHZ.

The areas suitable for growing olive in China are mainly in the western subtropical regions. Wudu District in Longnan city, located in the low mountain valley of Bailongjiang River on the south slope of Western Qinling, has become one of the most suitable regions for planting olive in China due to its suitable climate and soil characteristics (Shi *et al.,* 2011; Wang *et al.,* 2019). The pH values of soil from the five orchards were higher than 8.0; and the moisture contents, total nitrogen, organic matter, available phosphorus, and major metal elements were different due to soil texture, irrigation, fertiliser management, and other climate and soil factors. The suitable climate, soil, and altitude provide Wudu District with the basic conditions for olive plantation and cultivation.

Biological characteristics of olive fruits

The WSF of various cultivars and orchards ranged from 1.52 to 6.20 g. With regard to the five cultivars, the weight of Picholine was relatively high, ranging from 2.63 to 6.20 g, while that of Leccino was low (1.53 - 2.77 g). The difference in WSF was not related

to either MCF or SCF. This difference in WSF could be attributed to the vigour of tree, adequate nutrients, availability of soil moisture, crop density, and fruit leaf ratio, since it has been proved to influence fruit weight (Haggag *et al.,* 2013). In SHZ, the WSF of Frantoio, Ezhi-8, and Picholine did not show any significant difference ($p > 0.05$), but a significant difference in Coratina (4.65 g) and Leccino (2.18 g) was observed. In BHQ, the four cultivars showed a significant difference ($p < 0.05$). In DJB, Frantoio, Leccino, and Ezhi-8 showed no significant difference ($p > 0.05$), except for Picholine (6.16 g) and Coratina (4.82 g). Considering the different orchards, the average WSF in DJB was the highest (3.85 g), while ZZP had the lowest fruit weight (2.15 g). The results suggested that the variation of WSF of Coratina at different orchards was the most significant. However, the difference of Frantoio fruit weight was the least significant.

The FLD ranged from 1.63 cm (Leccino in ZZP) to 2.62 cm (Coratina in LTC), whereas, the FTD ranged between 1.16 cm (Leccino in BHQ) and 1.86 cm (Picholine in DJB). Picholine and Coratina had relatively large FLD and FTD, while Leccino had relatively small. In the same orchard, such as in DJB, the FLD and FTD between Picholine and Coratina showed no significant difference ($p > 0.05$); and Frantoio, Leccino, and Ezhi-8 showed no significant difference ($p > 0.05$) as well. With regard to the same cultivar, for example Ezhi-8, the FLD and FTD in different orchards showed no significant difference ($p > 0.05$). This indicated that the FLD and FTD of the five cultivars and orchards showed certain difference. Nevertheless, the FSI of most cultivars was around 1.4.

Ezhi 8 is a dual-use cultivar of oil and table olive bred by Chinese forestry experts. The other four cultivars were introduced from abroad, among which Leccino, Frantoio, and Coratina were from Italy, and Picholine was from France. These five olives are all appraised as excellent cultivars suitable for planting in Longnan (Deng, 2014). In terms of the fruit sizes of the five cultivars, Ezhi 8, Leccino, Frantoio, and Coratina are generally small, while Picholine is large. The maturity stage of Coratina is relatively late, which is in the middle and late November, while the other four cultivars are from late October to early November. The four olive cultivars introduced and cultivated in Longnan are comparable to their origin cultivars in the external quality and biological characteristic of fruit (Deng, 2014).

As far as we know, biological characteristics of olive fruit are influenced by many factors, including cultivar, environmental conditions, soil, fertiliser, and stage of ripening (Youssef *et al.,* 2010; Hbaieb *et al.,* 2017). Previous findings indicated that shaded fruits developed at a slow rate and were characterised by late dark going time, reduced size, and oblong shape, suggesting that light plays an important role in fruit growth (Bartolini *et al.,* 2014). The weight and shape of olive fruit were mainly affected by cultivar and genotype; meanwhile, the quality of olive fruit was impacted by geographical location, soil, irrigation, and fertilisation.

Biochemical components of olive fruits

Biochemical compositions of olive fruits are influenced by many factors such as cultivar, soil, fertiliser, and stage of ripening. In the tested olive fruit samples, SCF ranged between 70.62% (Leccino in ZZP) and 88.53% (Picholine in DJB), and also showed significant difference ($p < 0.05$). Picholine and Coratina had relative higher SCF, but Leccino and Ezhi-8 had lower SCF. In the five selected orchards, SCF in different cultivars from DJB and LTC had relative higher sarcocarp proportions, while ZZP was the lowest. The results also suggested that the quality of olive fruits depends on the genotype of olive and cultivation management.

The SCF from all cultivars and orchards were higher than 70%, among which Picholine was the highest (82.15%), while Leccino was the lowest (76.23%). The results suggested that genetic potential of the cultivar plays a leading role in SCF. However, the SCF of the same cultivar also varied in different orchards. The SCF from DJB and LTC was relatively high, and the SCF of most cultivars were more than 80%. From the analysis of the sampling altitude, it was concluded that the altitudes of DJB and LTC may be another geographic factor that influence the SCF.

Figure 1A shows the MCF in different orchards and cultivars. All of the MCF exceeded 40%. Among the five olive cultivars, Picholine had relatively higher average MCF, and Frantoio the lowest. MCF of Frantoio and Picholine in the five orchards was 41.69 - 54.54% and 50.17 - 68.50%, respectively. MCF of Coratina in four orchards ranged within 51.84 - 55.25%. Between different orchards, the MCF of the five olive cultivars in DJB was the highest. The results indicated that the MCF difference of Picholine in five orchards was the biggest, while Coratina was the smallest.

Generally, all the five olive cultivars from different orchards exhibited a good OOC production (Figure 1B). The OOC was closed to or exceeded 50%, and ranged from 49.25% (Coratina in ZZP) to 71.11% (Frantoio in DJB). The OOC of Frantoio was the highest in the five cultivars, ranging from 67.51 to 71.11%. The OOC of Leccino, Ezhi-8, and Picholine in the five orchards ranged within 53.09 - 67.09%, 53.69 - 62.21%, and 49.25 - 79.68%, respectively. The OOC of Coratina in the four orchards ranged within 49.27 - 68.47%, differing significantly from each other. Based on the average OOC in the olive cultivars, the order was:

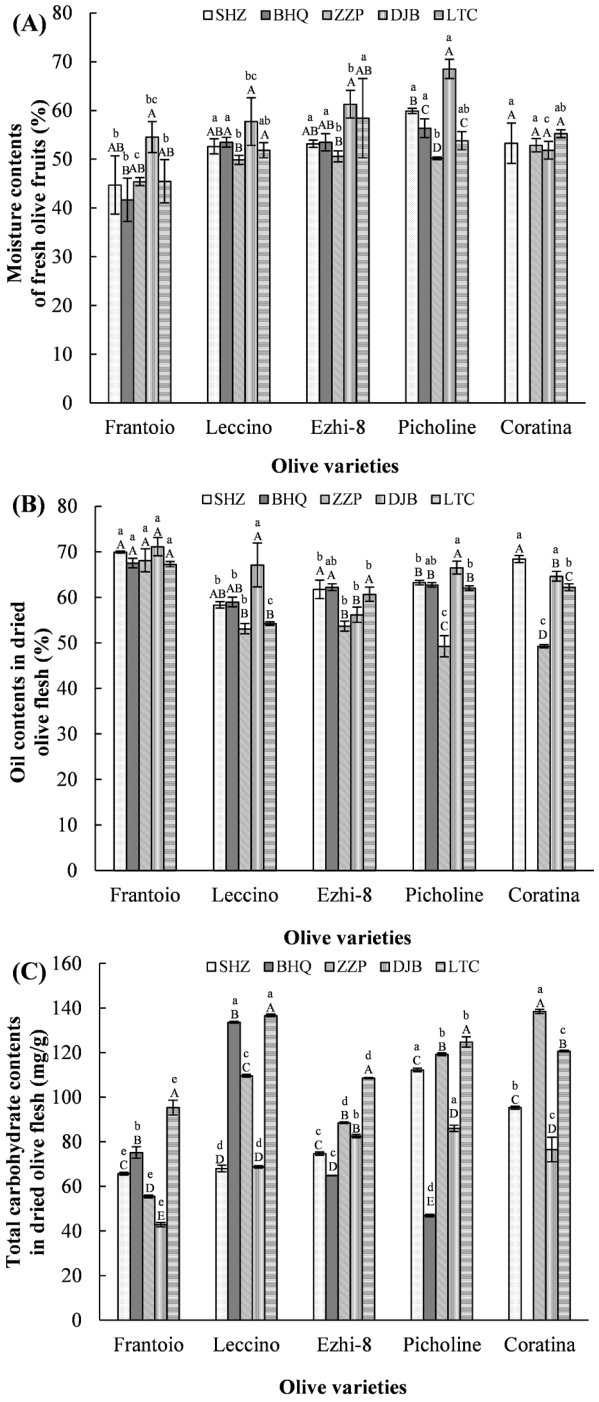

Figure 1. Biochemical compositions in olive sarcocarp from different cultivars and orchards (n = 3). Lowercase letters indicate significant difference among different cultivars in the same orchard, and uppercase letters indicate significant difference among different orchards for the same cultivar ($p < 0.05$).

Frantoio > Picholine > Coratina > Ezhi-8 > Leccino. Different olive cultivars had the lowest OOC in ZZP. It could be seen that Frantoio had approximately 70% of oil production in the five orchards. Frantoio, Leccino, and Picholine had the highest percentage of oil production in DJB. Thus, it can be concluded that the maximum production of OOC is primarily determined by the type of cultivar.

As shown in Figure 1C, the TCC in olive sarcocarp ranged from 42.82 mg/g (Frantoio in DJB) to 138.45 mg/g (Coratina in ZZP). The TCC in different cultivars and orchards showed significant differences. The TCCs of Frantoio, Leccino, Ezhi-8, and Picholine in five orchards were 42.82 - 95.35, 68.00 - 136.70, 64.82 - 108.55, and 46.89 - 124 mg/g, respectively. As compared to the data from Figures 1B and 1C, the correlation analysis results implied that there was a certain negative correlation between TCC and OOC. For Frantoio, Leccino, and Coratina, the correlation coefficients between TCC and OOC were -0.779, -0.612, and -0.808, respectively.

The above results suggest that the main biochemical components of olive fruits are related to cultivar, properties of planting soil, and fertiliser. Similar results were reported by Lavee and Wodner (2004), who concluded that the relative oil content in the mesocarp at full maturation will reach a uniform level, based on the genetic-environmental conditions regardless of fruit size and tree load. The results from Pouliarekou *et al.* (2011) showed that both the genetic factor and environmental conditions may be used to classify olive oils. Previous work reported that oil yield was positively associated with both fruit number and fruit fresh weight, but not with fruit oil concentration. The highest fruit fresh weight matched the highest fruit oil weight over a wide fruit size range; at the same time, both variables were highly related to oil yield (Trentacoste *et al.,* 2010).

Overall, as shown in Figure 1, the MCF of different orchards and cultivars were about 50%, and OOC was around 60%, while the TCC greatly varied. Moreover, there was a negative correlation between OOC and TCC in olive sarcocarp. It can also be seen from the WSF, SCF, and OOC of the tested cultivars that the olives introduced into and planted in Longnan showed better production performance as compared with the region of origin (IOC, 2000; Deng, 2014), indicating that Longnan is more suitable for olive cultivation (Deng *et al.,* 2016).

Bioactive constituents of olive fruits

The contents of bioactive constituents (total flavones, polyphenols, and saponins) in olive fruits from different cultivars and orchards are presented in Figure 2. It is apparent that the TFC in defatted and dried olive sarcocarp from the five cultivars and orchards were significantly different ($p < 0.05$). The TFC in Coratina sarcocarp (70.48 - 95.74 mg/g) was the highest as compared to the other four samples from the perspective of cultivar. However, between orchards, the TFC of Frantoio, Leccino, Ezhi-8, and Picholine cultivated in BHQ was the lowest

(9.59, 18.78, 9.75, and 23.37 mg/g, respectively), while, the TFC in LTC was the highest.

It can be seen from Figure 2B that the TPC in sarcocarp showed a more remarkable variation than TFC in view of cultivars and orchards. The TPC of the same cultivar varied significantly among different orchards, and the TPC in the same orchard varied between cultivars. There is, however, some regularity to the difference. The TPCs of the five cultivars from DJB were generally lower, while the TPCs from SHZ and LTC were relatively higher. In view of cultivar, the TPC in Coratina was still higher (12.28 - 23.20 mg/g). The results show that the difference of TPC is not only related to olive cultivar, but also fruit maturity and planting place.

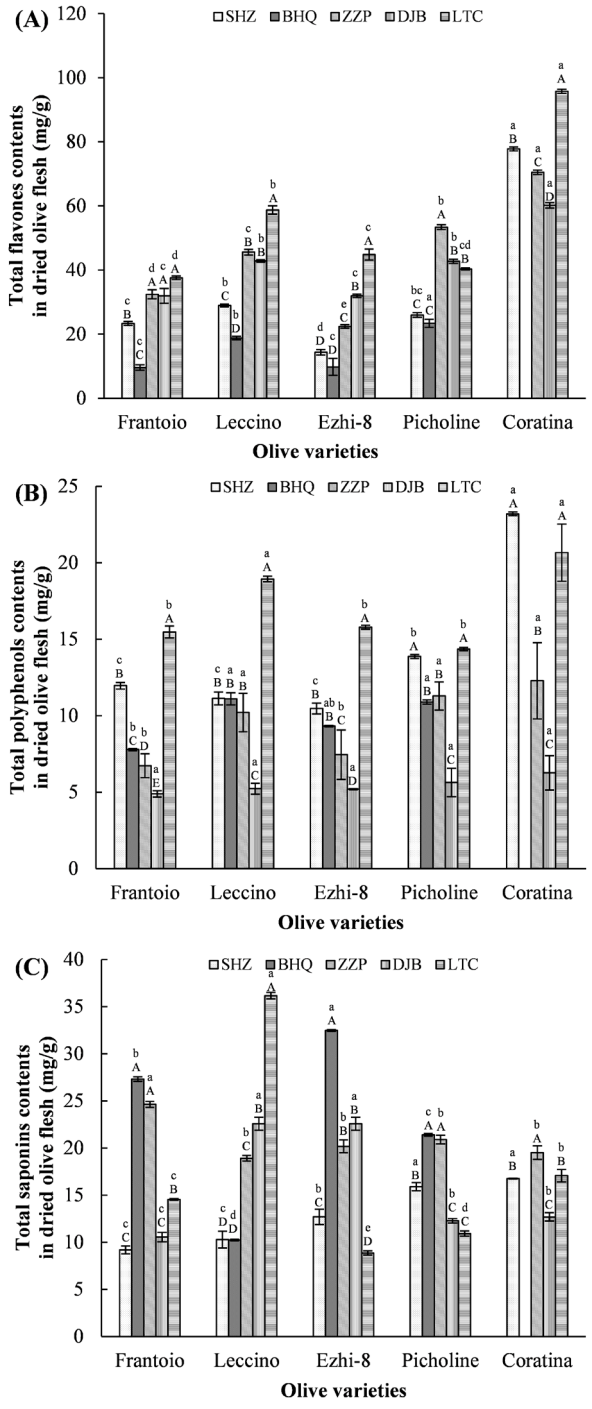

Figure 2. Functional compounds in olive sarcocarp from different cultivars and orchards (n = 3). Lowercase letters indicate significant difference among different cultivars in the same orchard, and uppercase letters indicate significant difference among different orchards for the same cultivar ($p < 0.05$).

Saponins are a class of secondary plant metabolites known to have antibiotic properties and protect against hypercholesterolemia, and also have various medicinal values such as anti-inflammatory, anti-diabetic, and central nervous system activity (Abbas *et al.,* 2015). In the present work, the TSC in olive fruits of various cultivars significantly differed. Figure 2C shows the changes of TSC in freeze-dried olive sarcocarp. The TSC in dried and defatted sarcocarp samples ranged from 8.86 to 36.16 mg/g. Although the TSCs of olive fruits from different cultivars and orchards were significantly different, the change rule was not obvious.

The Mediterranean diet is known for its health benefits, especially given by the large amount of polyphenols present in fruits, vegetables, oilseeds, and olive oil (Benavente-García *et al.,* 2000; Nakbi *et al.,* 2010). Several factors are known to affect the quantitative phenolic profiles of olive fruits. Factors such as the degree of ripeness, geographical origin, and nature of the cultivar have a pronounced impact on the composition of olive fruit. Vinha *et al.* (2005) analysed the phenolic compounds in 29 samples of olive fruits collected from north and central Portugal. The analyses showed that all samples presented a similar profile, which included at least six identified phenolic compounds (hydroxytyrosol, luteolin 7-O-glucoside, oleuropein, rutin, apigenin 7-O-glucoside, and luteolin), and the major compounds were hydroxytyrosol and oleuropein. Cecchi *et al.* (2013) reported the evolution of the phenolic profile in olive fruits of three typical Tuscan cultivars (Frantoio, Moraiolo, and Leccino) during the ripening period. They found that the total phenolic compounds in olive fruits were different in terms of cultivars and ripening stages. The results showed a wide range of variability in the TPC in olive sarcocarp across orchards. Following the TPC parameter, as shown in Figure 2B, the highest value was found to be 23.2 mg/g in Coratina. Coratina recorded the maximum TPC in all the orchard. The present work showed that the TPC in olive fruit exhibited certain cultivar dependence. The characters, biochemical constituents, and quality of olive fruits were different owing

to the cultivar, planting conditions, and maturity. Therefore, the suitable harvesting time should be determined based on the growth characteristics and maturity of different olive cultivars. The results also suggested that although the olive fruits were rich in polyphenols and flavonoids, the amount of phenols in olive oil was relatively low. This indicates that most water-soluble bioactive phenolic compounds that can be exploited and utilised in olive fruits are lost as processed wastes (Araújo *et al.,* 2015).

PPO activity in olive fruits

Differences in PPO activity in olive fruit from five orchards and cultivars are shown in Figure 3. The activities of PPO in five olive fruits ranged from 15.56 to 350.00 U/(g·min). The PPO activities of Frantoio, Leccino, Ezhi-8, Picholine, and Coratina in the five orchards were between 28.89 - 266.11, 42.67 - 325.00, 52.22 - 350.00, 18.89 - 62.22, and 15.56 - 26.11 U/(g·min), respectively. In different orchards, the PPO activity of olive fruits showed significant difference especially in Frantoio, Leccino, and Ezhi-8. For instance, the PPO of Ezhi-8 in different orchards showed significant difference ($p < 0.05$). In addition, those three cultivars had relative higher PPO activity as compared to Picholine and Coratina. The PPO activities in Picholine and Coratina were lower, and there was less difference in the five orchards. By analysing the TPC (Figure 2B) and PPO (Figure 3) in olive fruits, it was found that there was a certain negative correlation between them. The correlation coefficients of TPC and PPO in Leccino, Picholine, and Coratina were -0.954, -0.917, and -0.980, respectively. The correlation coefficient of average TPC and PPO in different orchards was -0.749. The results show that TPC in olive fruit may be related to the activity of PPO due to its enzyme-mediated oxidation.

As can be seen in Figure 2, olive fruits were rich in phenols and flavonoids, and there were significant differences among different cultivars and orchards. For example, the TFC and TPC in Coratina were relatively high, while the TFCs of the four cultivars from BHQ were low, so was the TPC of DJB. The data (Figure 3) showed that PPO activity was significantly different, while the PPO activity of Picholine and Coratina was low. These differences imply that while fruit cultivars determine the content of bioactive substances, different soil and nutritional factors also affect the synthesis of these substances. In addition, fruit maturity is also an important factor affecting its content. Hbaieb *et al.* (2017) reported that the olive PPO activity was greatly impacted by the cultivar and ripening degree of olive fruits. Thus,

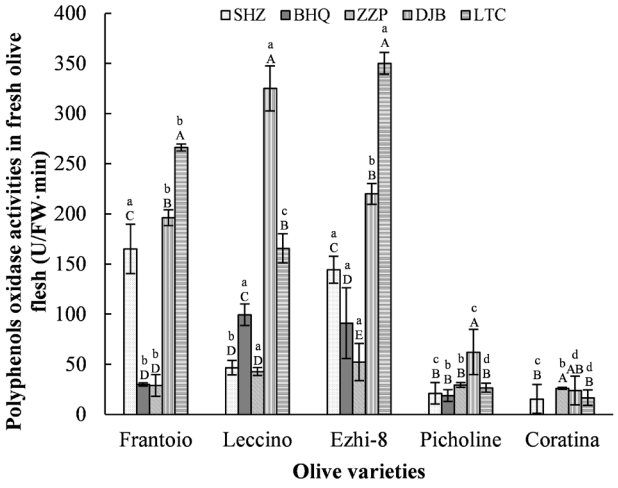

Figure 3. Polyphenols oxidase (PPO) activity in olive sarcocarp from different cultivars and orchards ($n = 3$). Lowercase letters indicate significant difference among different cultivars in the same orchard, and uppercase letters indicate significant difference among different orchards for the same cultivar ($p < 0.05$).

it is necessary to further investigate the evolution of phenolic compounds and phenolic redox enzymes (polyphenol oxidase, peroxidase, and phenylalanine ammonia-lyase) in olive fruit and their relationship.

Correlation and principal component analysis (PCA)

In order to further clarify the relationship between soil nutrient factors and fruit quality parameters, we conducted a correlation analysis, and the results are shown in Table 1. Data showed that there was a significant positive correlation ($p < 0.01$) between the contents of Ca^{2+} and Mg^{2+} in soil, while there was a significant negative correlation ($p < 0.01$) between the two ions and the pH value of soil. This indicates that the pH value of soil exerts a big influence on the contents of Ca^{2+} and Mg^{2+} in soil. There was a significant positive correlation ($p < 0.01$) between TNC and TOC in soil. Moreover, these two parameters (TNC and TOC) were significantly positively correlated with RAP ($p < 0.01$) as well as with FSI ($p < 0.05$), indicating that TNC and TOC can affect the RAP in soil and also the fruit size and shape.

WSF was significantly positively correlated with FLD, FTD, FSI, SCF, MCF, and OOC, indicating that the weight of olive fruit directly affects the shape parameters, sarcocarp, and olive oil content. Furthermore, the higher the SCF, the higher the OOC and MCF. A negative correlation was observed between FSI and SCF, as well as between MCF and OOC, which suggested that oval fruits had more sarcocarp, water, and oil contents than oblong ones. There was a significant negative correlation between

Table 1. Correlation analysis of the tested parameters of soil and olive fruit characters.

	pH	MCS	TNC	TOC	RAP	Mg	K	Ca	WSF	FLD	FTD	FSI	SCF	MCF	OOC	TCC	TFC	TPC	TSC	PPO
pH	1	0.265	-0.155	0.118	-0.111	-0.763**	-0.066	-0.709**	0.133	0.112	0.188	-0.136	0.161	0.013	0.039	0.150	0.113	-0.067	0.159	0.232
MCS	0.265	1	0.045	0.139	-0.115	-0.312	-0.237	-0.171	-0.044	-0.176	-0.191	0.143	-0.021	0.023	-0.046	-0.205	-0.133	-0.440*	0.273	0.158
TNC	-0.155	0.045	1	0.933**	0.717**	0.045	0.096	-0.016	-0.299	-0.275	-0.374	0.460*	-0.356	-0.296	-0.336	0.109	0.260	-0.019	0.062	-0.294
TOC	0.118	0.139	0.933**	1	0.657**	-0.215	0.046	-0.243	-0.308	-0.307	-0.384	0.455*	-0.381	-0.239	-0.405*	0.198	0.269	-0.126	0.119	-0.225
RAP	-0.111	-0.115	0.717**	0.657**	1	0.180	-0.005	0.036	-0.075	-0.028	-0.066	0.214	-0.111	-0.258	-0.253	0.301	0.233	0.330	0.055	-0.202
Mg	-0.763**	-0.312	0.045	-0.215	0.180	1	-0.221	0.880**	0.036	0.046	0.029	-0.010	-0.010	0.021	0.107	-0.028	-0.051	0.424*	-0.171	-0.239
K	-0.066	-0.237	0.096	0.046	-0.005	-0.221	1	-0.374	0.002	0.071	0.010	0.116	-0.048	-0.384	0.248	-0.208	-0.053	-0.132	-0.170	0.100
Ca	-0.709**	-0.171	-0.016	-0.243	0.036	0.880**	-0.374	1	0.143	0.169	0.135	-0.043	0.126	0.108	0.163	-0.130	0.047	0.262	-0.188	-0.145
WSF	0.133	-0.044	-0.299	-0.308	-0.075	0.036	0.002	0.143	1	0.722**	0.879**	-0.621**	0.881**	0.415*	0.544**	-0.072	0.170	0.067	-0.253	-0.193
FLD	0.112	-0.176	-0.275	-0.307	-0.028	0.046	0.071	0.169	0.722**	1	0.924**	-0.245	0.699**	0.268	0.364	-0.206	0.322	0.150	-0.092	-0.128
FTD	0.188	-0.191	-0.374	-0.384	-0.066	0.029	0.010	0.135	0.879**	0.924**	1	-0.575**	0.867**	0.407*	0.463*	-0.078	0.347	0.236	-0.145	-0.073
FSI	-0.136	0.143	0.460*	0.455*	0.214	-0.010	0.116	-0.043	-0.621**	-0.245	-0.575**	1	-0.695**	-0.455*	-0.432*	-0.099	-0.156	-0.276	0.149	-0.137
SCF	0.161	-0.021	-0.356	-0.381	-0.111	-0.010	-0.048	0.126	0.881**	0.699**	0.867**	-0.695**	1	0.451*	0.596**	-0.004	0.274	0.187	-0.309	0.018
MCF	0.013	0.023	-0.296	-0.239	-0.258	0.021	-0.384	0.108	0.415*	0.268	0.407*	-0.455*	0.451*	1	-0.055	0.131	0.136	-0.089	-0.184	0.144
OOC	0.039	-0.046	-0.336	-0.405*	-0.253	0.107	0.248	0.163	0.544**	0.364	0.463*	-0.432*	0.596**	-0.055	1	-0.471*	-0.206	-0.050	-0.364	0.134
TCC	0.150	-0.205	0.109	0.198	0.301	-0.028	-0.208	-0.130	-0.072	-0.206	-0.078	-0.099	-0.004	0.131	-0.471*	1	0.501*	0.570**	-0.019	-0.112
TFC	0.113	-0.133	0.260	0.269	0.233	-0.051	-0.053	0.047	0.170	0.322	0.347	-0.156	0.274	0.136	-0.206	0.501*	1	0.473*	-0.026	-0.169
TPC	-0.067	-0.440*	-0.019	-0.126	0.330	0.424*	-0.132	0.262	0.067	0.150	0.236	-0.276	0.187	-0.089	-0.050	0.570**	0.473*	1	-0.011	-0.098
TSC	0.159	0.273	0.062	0.119	0.055	-0.171	-0.170	-0.188	-0.253	-0.092	-0.145	0.149	-0.309	-0.184	-0.364	-0.019	-0.026	-0.011	1	-0.171
PPO	0.232	0.158	-0.294	-0.225	-0.202	-0.239	0.100	-0.145	-0.193	-0.128	-0.073	-0.137	0.018	0.144	0.134	-0.112	-0.169	-0.098	-0.171	1

** = Significant correlation at 0.01 level; * = Significant correlation at 0.05 level.

Table 2. Eigenvectors of correlation matrices of six leading principal components.

Characteristics	Principal components					
	1	2	3	4	5	6
SCF	0.900	0.051	0.251	0.114	0.103	0.135
FTD	0.896	0.122	0.287	0.177	0.101	-0.143
WSF	0.856	0.073	0.220	0.239	0.216	0.031
FLD	0.741	0.134	0.214	0.316	0.165	-0.263
FSI	-0.737	0.014	-0.137	0.245	0.124	-0.133
TOC	-0.662	0.235	0.485	0.326	0.225	0.261
OOC	0.632	-0.199	-0.253	0.458	-0.122	0.089
TNC	-0.628	0.427	0.293	0.423	0.211	0.248
MCF	0.498	-0.013	0.100	-0.444	0.331	0.405
Mg	0.129	0.720	-0.627	-0.041	0.068	-0.006
TPC	0.196	0.668	0.189	-0.286	-0.426	-0.216
Ca	0.245	0.624	-0.610	-0.065	0.266	0.061
RAP	-0.346	0.590	0.362	0.303	0.056	0.126
PPO	0.068	-0.462	-0.085	-0.222	-0.308	0.431
pH	0.077	-0.545	0.689	-0.108	-0.053	-0.083
TFC	0.147	0.484	0.616	-0.088	-0.042	0.010
K	-0.050	-0.207	0.020	0.645	-0.565	-0.045
TCC	-0.126	0.428	0.514	-0.526	-0.300	0.092
MCS	-0.177	-0.466	0.094	-0.077	0.611	0.101
TSC	-0.317	-0.121	0.168	-0.204	0.322	-0.701

TCC and OOC; TCC, however, was positively correlated with TPC and TFC, which shows that the sugars in fruits play an important role in the synthesis of lipids, polyphenols, and flavonoids (Conde *et al.,* 2008). The results suggest that TCC, OOC, TPC, and TFC may be used as important indexes to evaluate the quality of olive fruit.

For the aim of exploration of the external and internal factors that affect and determine the quality of olive fruit, we performed the PCA of relevant parameters, and the results are shown in Table 2. Through dimensionality reduction analysis of the external and internal factors affecting the quality of olive fruit, the principal components were extracted. The contribution rates of the first, second, and third principal components were 26.673, 16.113, and 13.746%, respectively. Besides, the cumulative contribution rate of the first six principal components to fruit quality was over 80%. These six components contained most of the information of olive fruit and could fully reflect the overall quality of fruit, so the first six principal components can be selected for analysis, especially the first three.

As shown in Table 2, the principal eigenvector could reflect the contribution rate of each index to the principal component (Wang and Xing, 2017). The first principal component mainly included the information of SCF (0.900), FTD (0.896), WSF (0.856), FLD (0.741), and OOC (0.632) of olive fruit, which implies that the first principal component can be divided into the biological characteristics of olive fruit from the eigenvectors. This result further indicates that the genotype and internal characteristics of fruit are the main factors determining the quality of olive fruit. The second principal component mainly included the information of Mg^{2+} (0.720), Ca^{2+} (0.624), RAP (0.590), TNC (0.427) of soil, TPC (0.668), and TFC (0.484) of olive fruit, while the third included the information of pH (0.689), TOC (0.485), RAP (0.362) of soil, TFC (0.616), and TCC (0.514) of fruit. This indicates that the second and third principal components include the information of both soil nutrition and the bioactive components in olive fruits. The fourth and fifth principal components mainly included the information of soil K^{+} (0.645) and MCS (0.611), respectively. The results of PCA show that the biological parameters such as fruit size, weight, sarcocarp ratio, moisture, and oil content are the first principal components that determine the quality of olive fruits, meanwhile, the nutritional and physicochemical properties (Mg^{2+}, Ca^{2+}, K+, RAP, TNC, pH, and MCS) of the planting soil, and the bioactive components such as saccharides, flavonoids, and phenols in olive fruit also affect their quality.

The results of PCA would be ideal when top

two or three of principal components can explain the majority of variation. However, our results show that the cumulative contribution rate of the first six principal components to be 80.12%, which implies that the variables affecting olive fruit quality were not concentrated and included the information of biological characteristics, bioactive ingredients in olive fruit, and soil nutrient factors. The results of PCA also indicate that the factors affecting the quality of olive fruit are complex.

Conclusions

In the present work, the olive fruits' quality of five main cultivars grown in different orchards in Longnan, China was evaluated from morphology and biochemistry level. Due to the differences in cultivars, maturity, water, and fertiliser management of orchards, there are significant variations in the biological characteristics, and physiological and biochemical quality of olive fruits. For biological characteristics, appearance quality, lipid content, polyphenols, flavonoids, and other ingredients of olive fruits, the five main olive cultivars showed good production performance and nutritional quality. Thus, conclusion can be drawn that Longnan is suitable for olive cultivation. The PCA results indicate that the quality of olive fruits can be evaluated principally by analysing the main biological characteristic parameters (pulp content, fruit size, and weight) and the bioactive components (lipids, carbohydrates, polyphenols, and flavonoids). Moreover, the physicochemical properties and nutrients of planting soil include Mg^{2+}, Ca^{2+}, pH; and available phosphorus and total nitrogen also affect the quality of olive fruits.

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