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Article

Modulation of the Irrigation Practices in Croatia for More Sustainable Olive Growing

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Abstract: Olive groves in the Mediterranean may lose production sustainability because of their vulnerability to climatic change. Irrigation is an important measure that could significantly affect fruit yield, olive fruit fly infestation, and oil characteristics. The aim of paper was to compare the regulated deficit irrigation with different water management practices, in consecutive years, in two locations in Zadar County (Croatia), affecting fruit morphology, olive fruit fly infestation, and quantity and quality of the extracted Coratina cultivar oil. Treatments, namely C—rainfed, T_1—deficit irrigation (produce's practice), T_2—regulated deficit irrigation, and T_3—full irrigation (100% ECTO), were established. Irrigated treatments had a positive effect on all morphological characteristics of the fruit. The pulp mass, independently of the year, increased in irrigated treatment (ranging from 1.04 to 1.65 in C to 2.25 and 2.30 in the irrigated treatments) and resulted in a higher oil content on a fresh weight basis (ranging from 16.39% to 17.85% in C to 19.48% to 23.26% in the irrigated treatments). However, fruit yield per tree was only location-dependent. When olive fruit fly presence was high, fruit infestation was greatest in the irrigated compared to the rainfed treatment. According to quality parameters, all oils were classified as EVOO. Individual phenols were influenced by irrigation, while the composition of fatty acids was more influenced by location than treatment. The sensory characteristics of the resulting oil were slightly reduced compared to rainfed treatment. The results indicate that regulated deficit irrigation benefits water use sustainability without compromising the quality of the oil.

Keywords: climate change; irrigation management; olive fruit; olive fruit fly; olive production; oil quality and composition

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1. Introduction

Olive (*Olea europaea* L.) is an important species cultivated on over 11 million hectares of land globally (2017) [1]. In the Mediterranean, it represents an important ecological and socioeconomic fruit species [2,3], where over 92% of world's olive oil is still produced from the total annual production, which in 2021/2022 amounted to 3398.000 tons of oil [4]. The olive fruit has a dual purpose: it is used for canning as table olives or as a raw material for the production of olive oil. The consumption of these products is globally increasing due to their seasonal, culinary, and nutritional values [5,6]. Extra virgin olive oil (EVOO) is the most important oil of the highest grade and is extracted from fresh and healthy olive fruits [7,8]. The stages of olive fruit growth and development are typical [9] and dictated by genetic, agronomic factors, and geography and the interaction of these factors [3,6,10,11]. Since olive oil (VOO), as opposed to other vegetable oils, is extracted at low temperatures using only physical procedures (grinding, centrifugation, and separation), the composition and quality of the extracted oil directly depends on the composition and the quality of the olive fruit harvested [12,13].

Irrigation is a practice that has a positive impact on the olive trees. In intensive orchards, it is almost a common practice. It can alleviate certain disadvantages related to olive fertility [14]. For example, deficient irrigation on Arbequina and Arbosana olive varieties can save a significant amount of water, for about 30% of the applied irrigation water, while on the other hand, it affects the increase in quality because the amount of aromatic compounds related to the green odor increases (hexanol, trans-2-hexen-1-ol, hexanal) and affects the composition of fatty acids [15]. Irrigation in olive cultivation directly affects the yield, composition, and quality of extracted VOO [6,15,16]. This has been well documented in a number of studies [17–19]. However, irrigation is not regularly used in Croatia because domestic olive cultivation is characterized by a high diversity of agro-ecological conditions on a relatively small scale, in which the traditional method of cultivation prevails with large fluctuations in yield [20] despite the high diversity of locations in which olive cultivation occurs. Olive growers face significant difficulties in determining when to commence irrigation and how much water to use (irrigation outbreak and application rate), which often results in excessive irrigation practices. This, on the other hand, can lead to unintentionally reduced yield as well as increased production costs and negative environmental effects.

In the Mediterranean, two climatic factors strongly affect olive yield: drought and extreme high temperatures [21–23]. It is predicted that climate change will have a developing effect on olive oil production [21,22,24]. Even though olive trees are well adjusted to a Mediterranean climate, it has been found that dry and hot summers adversely affect both the qualitative and the quantitative characteristics of olive oil [25]. In addition, excessive irrigation might also create a favorable environment for pests and diseases due to high soil humidity and large fruits [26].

The olive fruit fly (*Bactrocera (Daculus) oleae*, Gmelin, 1790) is a pest in olive growing areas worldwide and especially so in the Mediterranean basin [25–28]. Depending on the geographic location, olive fruit fly may cause fruit infestation of up to 100% of the produce if left untreated [29]. It was found that temporal and spatial differences due to the weather pattern, elevation, and distance to the sea also influence infestations [30]. Olive fruit fly is particularly serious in irrigated orchards, where the high relative humidity is favorable for its biology, and the large olive fruits are attractive for oviposition [26] and/or are therefore infested sooner [31]. High soil moisture (particularly in irrigated orchards) may result in turgid fruits that are particularly subject to pests and diseases [26]. In contrast, the wilting process makes fruits less susceptible to the attack of olive fruit fly because of turgor loss, and prolonged water shortages lead to premature fruit drop [32]. In a study by [33], the olive fruit fly infestation level of each olive cultivar investigated tended to be both earlier and slightly higher under irrigated conditions than under natural rainfed conditions. Studies on *B. oleae* abundance have been conducted mainly on autumn populations. According to Marchi et al. [32], the implementation of tools that predict the behavior of *B. oleae* on a broad scale should take the influence of a warming-induced enhancement of overwintering pupae survival into account for the future sustainable management of olive orchards.

Climate warming is expected to increase the range of olive fruit fly northward and in coastal areas but decrease its range in the south. In Italy, the range of olive is expected to increase into currently unfavorable cold areas in higher elevations in the Apennine Mountains in central Italy and in the Po Valley in the north [34]. Therefore, while climate warming may extend the range of olive fruit fly into previously unfavorable colder areas at higher elevation, insect performance and fitness can be reduced in relatively hot areas that lack the thermal buffering influence of the sea (Marchi et al. [32], cit. Chessa and Delitala 1997). Water needs and the control of the olive fruit fly for olives to produce high-quality EVOO are influenced in the Mediterranean basin by abiotic factors such as precipitation and temperatures, and it seems that more advances in technology are needed to support farmers' decision making.

Present technologies in olive cultivation have been increasingly relying on the "smart agriculture" concept. Introducing smart agriculture technologies and using autonomous support systems has multiple benefits. One is being able to overcome system pressures induced by a lack of agricultural workers. The other is to enable precise and automated water rate application to olive trees, thus increasing water usage efficiency as well as the yield and the quality of the crop. Additionally, with the help of artificial intelligence (AI), algorithms can be used to filter the data directly derived from biotic measurements, which will help the producer to make informed management decisions [35], but that model must be created with a sufficient quantity of real data collected in the field.

The Italian olive cultivar Coratina as a Mediterranean spread variety is becoming of greater interest to Croatian producers who strive for high-quality oil. The Coratina cultivar has consistently high productivity and yield as well as the relatively high proportion of oil in the fruit. Since there are limited empirical data on the impact of irrigation on Coratina in Croatia, this work explores this.

Therefore, the aim of this work was to determine how different water management changes over locality and time affected healthy fruit morphology and the infestation of fruit by the olive fruit fly, including the quantity and quality of VOO in the Coratina cultivar. Regarding the aim, study compares regulated irrigation deficit (SAN technology) with the other irrigation managements based on the qualitative parameters of olive oil.

2. Materials and Methods

2.1. Location Characteristics and Climatic Features

This research was conducted in two olive groves, namely (1) Novigrad (44°10′58.5″ N 15°33′30.8″ E) and (2) Žman (43°57′42.9546″ N 15°7′21.5358″ E) in Zadar County, Croatia, during the 2020 and 2021 growing seasons. The Novigrad olive grove is located at 70 m above sea level, extending over 2.5 ha and including 500 olive trees planted in 7 × 7 m plots; protection against harmful organisms is carried out according to the principles of the ecological system of cultivation. Olive trees from the Italian Coratina cultivar were investigated in both experimental fields. The start of irrigation at the Novigrad location is determined by the producer depending on the amount of precipitation, and in average years, it starts before flowering, i.e., at the end of April or at the beginning of May. In the growing season, from a decimal code for the growth stages BBCH (61–89) [36], the producer adds water in 10 irrigation portions.

The Žman olive grove is located at 52 m above sea level, extends over an area of 5 ha, and has 1100 trees in a 7 × 7 m planting scheme. In this plantation, one plot was selected for research. The olive grove is certified in an ecological system of production, where preparations for the suppression of harmful organisms are strictly monitored. The Žman cultivation area lacks water, as it is on an island. Irrigation is carried out using the "drop by drop" system. The functionality of this system is that it saves water and distributes it evenly in the targeted places of the root zone with low pressure. The start of irrigation is similarly determined as in the Novigrad location, whereby the producer determines it based on experience and depending on the prevailing weather conditions. The first irrigation usually starts before flowering, i.e., at the end of April or the beginning of May. Throughout the irrigation season, the producer, according to experience, adds different portions of water, not strictly uniform, through an average of 15 portions. Depending on the microlocation and the characteristics of the growing year, the start of irrigation is BBCH (61: beginning of flowering—68: majority of petals fallen or faded) and the end of irrigation according to the BBCH scale (79: fruit about 90% of final size—89: harvest maturity) [36].

The age of the plantations in both locations was 15 years, and the predominant form of cultivation was a free vase with three to four skeletal branches.

The climate in Novigrad, Zadar County, Croatia, is characterized as a moderately warm humid climate with hot summers [37]. In 2020, the total precipitation at this location was 676.5 mm, and in 2021, it was 825.9 mm (Figure 1). The average daily evapotranspiration (Eto), calculated based on data obtained from the Novigrad meteorological station in 2020, was 3.37 mm, and in 2021, it was 3.42 mm. The absolute maximum temperature in both years was 37 °C, and the absolute minimum was −0.8 °C in 2020 and −4.7 °C in 2021 [38]. Due to the characteristics of the climate, namely that it provided an insufficient amount of precipitation during the growth and fruit development season, irrigation was indispensable to the sustainability of olive cultivation in the years investigated in this study.

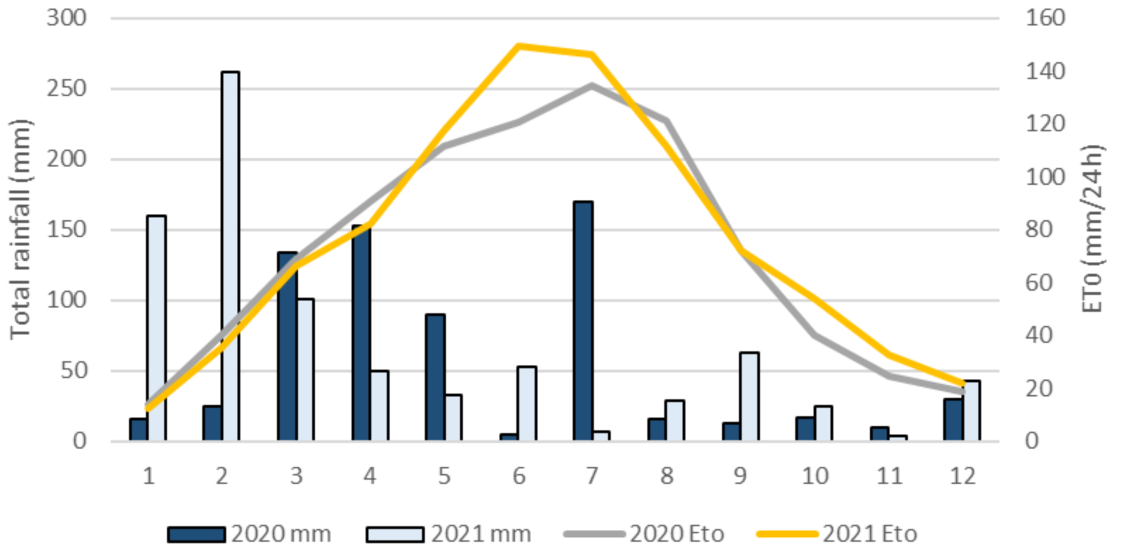

Figure 1. Monthly rainfall and monthly reference evapotranspiration in 2020 and 2021 from Novigrad, Zadar County. ETo, reference evapotranspiration (data collected from the PinovaMeteo meteorological station) [38].

Climatic conditions in Žman, Dugi Otok, are characterized by Mediterranean, subtype insular, eumediterranean with mild, rainy, and moderately windy winters and hot and dry summers [37]. Due to the extremely dry climate with insufficient rainfall experienced during the growth and fruit development season, irrigation is critical to ensure sustainability of olive cultivation. The total precipitation in 2020 was 804 mm, and in 2021, it was 784.4 mm (Figure 2). The average daily evapotranspiration (Eto), calculated from data obtained from the meteorological station in Žman, Dugi Otok, was 3.79 mm in 2020 during the irrigation season (April–October), and in 2021, was 3.46 mm. The absolute maximum temperature in Dugi Otok in both years was 39 °C. The absolute minimum temperature in Dugi Otok in 2020 was 0 °C, and in 2021, it was −2.1 °C [38].

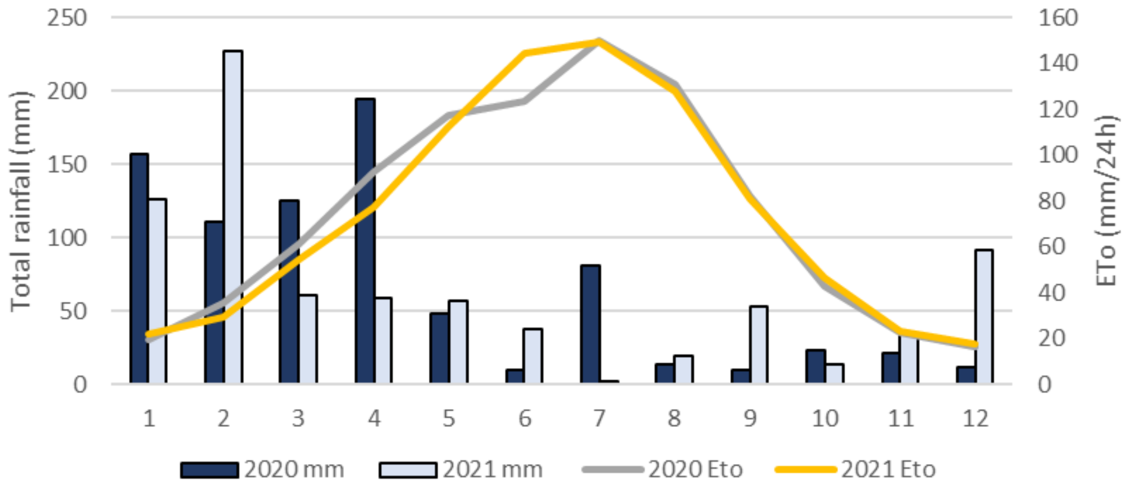

Figure 2. Monthly rainfall and monthly reference evapotranspiration in 2020 and 2021 from Žman, Dugi Otok, Zadar County. ETo, reference evapotranspiration (data collected from the PinovaMeteo meteorological station) [38].

2.2. Soil Characteristics

The guidelines for determining the ration and amount of water added during irrigation was established before the irrigation system was installed. Field pedological research consisted of data collection on internal and external morphological characteristics. The soils in both olive groves are karst soils on limestone, the formation of which was greatly influenced by anthropogenic processes i.e., over centuries rock surfaces were cleared, forests cleared, dry walls erected, and small terraces built.

For laboratory pedological analyses, soil was sampled from pedological profiles, and standard physical and chemical analyses were performed (Table 1). At Novigrad, the soil is a skeletal and powdery clay or powdery clay to powdery clay loam skeletonoid. At Žman, the soil is a skeletal and powdery clay in the upper part of the profile and skeletal clay loam in the lower part of the profile. The average soil depth is 20 cm higher at the Novigrad location. Fractions of coarse (2.0–0.2) and fine (0.2–0.063) sand and coarse powder (0.063–0.02) are represented in larger quantities at Žman, while fractions of fine powder (0.02–0.002) and clay (<0.002) are more prevalent in the Novigrad location (Table 1). The content of the soil skeleton is almost equal (Table 1).

Table 1. Mechanical composition of the soil, Zadar County, 2019.

Location	Depth cm	Mechanical Composition of Soil Fines in Na-Pyrophosphate, % Content of Particles, Diameter mm					Content of Soil Skeleton %
		Coarse Sand	Fine Sand	Coarse Powder	Fine Powder	Clay	
		2.0–0.2	0.2–0.063	0.063–0.02	0.02–0.002	<0.002	
Novigrad	0–60	4.96	5	17.22	29.58	43.24	49.12
Žman	0–40	8.3	7.2	22.85	24.4	37.25	48.7

Method: modified HRN ISO 11277:2011. cit.Husnjak et al. (2019) [39].

The basic physical properties of the soil at both locations are presented in Table 2. The water capacity of the soil at both locations was small to medium, the soil air capacity was very high, and the soil was porous (Table 2). Water permeability in Žman is very fast, while at Novigrad, it was not possible to determine this because of the soil texture.

Table 2. Basic physical properties of soil, Zadar County, 2019.

Location		Novigrad	Žman
Depth cm		0–60	0–40
Current humidity	vol%	19.9	26.25
Soil water capacity	vol%	33.6	33.5
	Evaluation	Small to medium	Small to medium
Soil capacity for air	vol%	20.1	20.25
	Evaluation	Very big	Very big
Total porosity	vol%	53.7	53.8
	Evaluation	Porous	Porous
Soil volume density φv	g cm^{-3}	1.14	1.23
Density of solid soil particles φč	g cm^{-3}	2.46	2.65
Water permeability	10–5 cm s^{-1}	NA *	2401.2
	interpretation		Very fast

NA *, samples could not be taken because of soil skeleton. Methods: current humidity soil (HRN ISO 11274:2004), water capacity and soil capacity for air (Gračanin, JDPZ, 1971), total porosity (calculation using soil densities, JDPZ, 1971), soil volume density (HRN ISO 11272:2004), density of solid soil particles (HRN ISO 11508:2004), and water permeability (Constant hydrostatic pressure method using device for serial determination of water permeability, JDPZ 1971) cit. Husnjak et al. (2019) [39].

Table 3 details the basic chemical properties of soil from the two localities investigated in this study. At the Novigrad location, the soil reaction (pH) was neutral to alkaline, and the soil was medium-carbonated and well supplied with humus. At Žman, the soil was alkaline, humus, and carbonate in character [39].

Table 3. Basic chemical properties of soil, Zadar County, 2019.

Location and Profile Number	Depth cm	Soil Reaction—pH			Total $CaCO_3$		Physiologically Active Calx CaO		Humus		Character of Humus
		H_2O	KCl	Category	%	Category	%	Category	%	Category	
Novigrad	0–60	7.91	7.22	Alkaline	13.7	Medium carbonated	7	Medium quantities	9.02	Large amounts of humus	Slightly acidic
Žman	0–40	7.93	7.25	Alkaline	21.3	Very carbonated	4.75	Small quantities	3.83	Sufficient amount of humus	Slightly acidic

Methods: soil reaction—pH (HRN ISO 10390:2005), total $CaCO_3$ (modified HRN ISO 10693:2004), physiologically active CaO (Galet JDPZ, 1966), humus (Tjurin JDPZ 1996), and character of humus (method with 2% NH_4OH, Škorić, 1982) cit. Husnjak et al. (2019) [39].

2.3. Experimental Design

There was a total of four treatments in the field experiment. The basic plot had an area of 30.3 m^2, represented with two olive trees. The treatments had three repetitions, and the total area per treatment was 90.90 m^2. A total of 24 trees with an area of 363.6 m^2 were included in the two locations (Žman and Novigrad) of the field experiment. Irrigation at the Novigrad location was carried out with a sprinkler system, with nozzles placed along the trunk at a height of 1.5 m, from the ground to the crown. The water used for irrigation was standard quality, without qualitative defects that would harm the plants and soil.

The treatments comprised the following:

C—Rainfed;
T_1—Deficit irrigation (producer's practice);
T_2—Regulated deficit irrigation (SAN—Technology);

T_3—Full irrigation (100% ECTO). (Irrigation treatments differed in the amount of added water and the irrigation rate number.)

The treatment of deficient irrigation T_1, without a defined regime, included the addition of water using the method of years of the producer's experience. The next treatment T_2, the second deficit, was installed using SAN technology and represents a different guidance of irrigation in certain phenological phases. Before flowering, fruit growth, and accumulation of oil in the fruit, the amount of added water was 80% ETc, and between the mentioned stages, it was irrigated with 50% ETc. Compensation of 100% of water lost by evapotranspiration (ETc) is represented by treatment T_3. It could be used to calculate the water saved by using other treatments. The control treatment (treatment C) represents rainfed trees.

Both olive groves had a Pinova TM meteorological station from which data were taken for irrigation calculations. The soil water capacity and the area around the trunk were determined via pedological analysis. Commencement of irrigation coincided with of the start of lentocapillary humidity. The water flow for each treatment was regulated by a digital water flow indicator (552059 digital water meter). The irrigation system covered the area in the width of the crown and contained multi-year irrigation pipes (PE 16 mm (3/4″)) with 30 drippers placed spirally around the trunk. This was carried out using the "drop by drop" irrigation system. Only the production practice (T_1) at the Novigrad location was irrigated with the described sprinkling system. The entire olive grove was under integrated production with an installed irrigation system. The above irrigation experiment was carried out over two years. The start dates of irrigation at Žman were 10 April 2020 and 25 May 2021, and the end dates were 18 August 2020 and 13 September 2021. At Novigrad, the starting irrigation dates were 6 April 2020 and 31 May 2021, and the end dates were 13 September 2020 and 5 September 2021.

Equations (1) and (2) were used to calculate the amount of water for irrigation:

$$\mathbf{IR} = \mathbf{ETc} - \mathbf{Ep} - \mathbf{R} \tag{1}$$

IR = The amount of water for irrigation;

ETc = Evapotranspiration;

Ep = Effective precipitation (used in the calculation was 70% of the total precipitation recommendation for olive trees grown in the Mediterranean);

R = Available water.

$$\mathbf{Etc} = \mathbf{ETo} \times \mathbf{Kc} \tag{2}$$

ETo = Reference evapotranspiration obtained from the PinovaMeteo meteorological station [38];

Kc = Corrective factor for olive trees. The Kc value for the months of March, April, and May was 0.76; for June it was 0.70; for July and August 0.63; for September 0.72; for October 0.77; and for November 0.75 [40].

The values of the water added to olive trees is shown in Table 4.

Table 4. The total amount of added water for irrigation for each tree by treatment (C, T_1, T_2, and T_3) and the number of rates in two years (2020 and 2021) and at two locations (Novigrad and Žman) in Zadar County, Croatia.

Year	Treatments *	Novigrad		Žman	
		Amount (l)	Rate Number	Amount (L)	Rate Number
2020	C	0	0	0	0
	T_1	685	9	1393	11
	T_2	1503	14	1261	19
	T_3	1945	14	1800	19

Table 4. *Cont.*

Year	Treatments *	Novigrad		Žman	
		Amount (l)	Rate Number	Amount (L)	Rate Number
2021	C	0	0	0	0
	T_1	600	6	762	4
	T_2	1085	11	676	10
	T_3	1585	11	1000	10

* Treatments: C, rainfed conditions; T_1, deficit irrigation (the usual producer's practice); T_2, deficit irrigation acquired by SAN technology in respect to phenological stages; T_3, irrigation with 100% of evapotranspiration (ETc) level; Amount (l), total amount of added irrigation water for each tree expressed in liters (l); Rate Number, number of irrigation rates during the year per treatment.

2.4. Determination of Yield, Morphological Characteristics of the Fruits, and Olive Oil Samples Production

Fruit harvesting for samples to determine yield and morphology and olive oil analysis took place on 12 October 2020 and 10 October 2021 at the Žman location and on 23 October 2020 and 17 October 2021 at the Novigrad location. In total, 40 healthy fruits randomly selected per tree, per year, and per single location and without visible damage were selected from the central part of the bearing branch [41]. The fruits were transported in a portable hand cooler in marked plastic bags, in order to lose as little water as possible, to the laboratory. They were kept at 4 °C pending further analyses.

The morphological measurements of fruits began with weight determination on a laboratory scale with a precision of 0.01 g (manufacturer: CAS Scale, Dhaka, Bangladesh). The length and width were measured using digital calipers (manufacturer: JIANGXI, Jiangxi, China). The pulp (mesocarp) of the fruit was carefully removed, and the stone (endocarp) was cleaned of the remaining pulp. It was weighed, and the length and width of the stone were measured. By subtracting the weight of the stone from the weight of the fruit, the weight of the pulp was obtained, and the proportion of the pulp was calculated according to the Equation (3):

$$\text{Pulp proportion} = \text{mass of pulp}/\text{mass of fruit} \times 100 \quad (3)$$

The part of the fruits that remained on the tree after sampling for morphological characterization was collected in the regular harvest. These fruits were then transferred to a 20 kg PVC crate and weighed in order to determine the nature per tree, i.e., per treatment. A technical digital scale model: Vertie® TD—8888 was used for this weighing.

Olive oil samples were obtained using the Abencor laboratory oil mill (MC2, Ingeniería y Sistemas, Sevilla, Spain) in triplicate for each treatment. Two (2) kg of healthy, undamaged fruits (with no signs of fly attack or other mechanical damage) were carefully manually sampled from the central marginal part of the canopy to obtain each oil sample that was used in further analysis of the quality of the Coratina cultivar olive oil. After the olive fruit grinding, samples of olive paste (50 g) were taken to determine the proportion of dry matter and oil in the olive fruit. The rest of the olive paste was malaxed in thermostat vertical mixers for 40 min at a temperature of 25 ± 1 °C. After malaxation, the olive paste was centrifuged for 90 s at a speed of 3500 revolutions/minute, and the oil together with the vegetable water was discharged into the separation cylinders (MC2, Ingeniería y Sistemas, Sevilla, Spain). The oil was separated from the plant water by decantation and centrifugation for 1 min at a speed of 4000 revolutions/min.

2.5. Monitoring Population and Determination of Fruit Infected by B. oleae

The monitoring of olive fruit fly populations was carried out using pheromone (Ferobank) -baited yellow sticky traps (Rebell amarillo, Andermatt Biocontrol Suisse). Yellow sticky traps measuring 21 cm × 17 cm with eight sticky sides were placed upon detection of the first appearance of the olive fruit fly in olive groves. Placement at both locations was on 26 June 2020 and 25 June 2021. The layout of the yellow traps was in the center of the tree crown. One trap was placed on every other tree, i.e., three traps per treatment. The number of olive fruit fly captures was determined by visual inspection of the trap after a 7-day period. During the flight period of adults, 12 inspections were performed in 2020 and more in 2021, i.e., 15, respectively. The last inspection was carried out at the Novigrad location on 6 October 2020 and 15 October 2021 and in Žman, Dugi Otok, on 12 October 2020 and 8 October 2021, after which time the yellow traps were removed.

Fruit sampling to determine the level of olive fruit fly infestation was carried out at both localities in both years. In each olive grove, on the day of harvest, samples of 100 fruits were taken for each replicate. First, fruits with individual holes were separated as well as fruits with purple-brown skin discoloration, which indicates an olive fruit fly attack. After a visual inspection, such fruits were opened using a knife, and the number of fruits attacked by the olive fruit fly (larvae, pupae, or the opening where the adult came out) was determined and recorded.

2.6. Oil Analysis

2.6.1. Oil Content and Oil Yield

Theoretical oil content in the fruit was determined according to the method described by Brkić et al. (2008) [42] in the olive paste samples collected after fruit milling using the Soxtec Avanti 2055 apparatus (Foss Tecator, Höganäs, Sweden).

Oil yield (%) was calculated multiplying by 100 the mass ratio of extracted oil (g) and olive paste (g) [43] using the following Equation (4) [43]:

$$\text{Oil yield (\%)} = \text{mass ratio extracted oil (g)/olive paste (g)} \times 100 \tag{4}$$

2.6.2. Virgin Olive Oils (VOOs)s Quality Parameters

VOOs quality parameters, free fatty acids (FFA) [44], peroxide value (PV) [45], and spectrophotometric indices (K_{232}, K_{270}, and ΔK) [46] were determined according to the International Olive Council (IOC) methods presented in the European Commission Implementing Regulation [47].

2.6.3. Analysis of Fatty Acid Methyl Esters (FAME)

FAME analysis was performed using a Varian 3.350 GC (Varian Inc., Harbor City, CA, USA) equipped with a Rtx-2.330 capillary column (Restek, Bellefonte, PA, USA) and a flame-ionization detector according to IOC method [48]. Identification of FAMEs was based on their retention times with respect to the standard FAME mixture (Sigma, Darmstadt, Germany) according to the IOC method [48]. Relative amounts of each fatty acids were expressed as proportions (%) of total fatty acids.

2.6.4. Analysis of Phenolic Compounds

Phenolic compounds in oil samples were extracted and analyzed using an HPLC Agilent Infinity 1260 System (Agilent Technologies, Santa Clara, CA, USA) and performed according to the method of Jerman Klen et al. [49], modified by Lukić et al. [50]. Identification of phenolic compounds was performed by comparing retention times and UV/vis spectra with those of pure standards and those from Jerman Klen et al. [49]. Detection was carried out at 280 nm (simple phenols, lignans, secoiridoids, and vanillic acid), at 320 nm (vanillin and p-coumaric acid), and at 365 nm (flavonoids). Quantification was performed using standard calibration curves made for tyrosol, hydroxytyrosol, vanillic acid, vanillin, p-coumaric acid, luteolin, apigenin, pinoresinol, and oleuropein. For hydroxytyrosol acetate, acetoxypinoresinol, and secoiridoids, semiquantitative analysis was performed, and the concentration was expressed as hydroxytyrosol, pinoresinol, and oleuropein, respectively, assuming a response factor equal to one. Concentrations of phenolic compounds were expressed as mg/kg oil. Total phenolic content was expressed as the sum of all the identified phenolic compounds.

2.6.5. Sensory Analysis of VOOs

Sensory analysis of VOO samples was performed according to the IOC method (IOC, 2018) [51] by the accredited and IOC-recognized panel for sensory assessment of VOO which consisted of eight trained assessors. Odor and taste characteristics were quantified using a 10 cm unstructured intensity ordinal rating scale ranging from 0 (no perception) to 10 (the highest intensity). In order to explain specific changes in sensorial profiles of oils, a modified evaluation sheet expanded with specific odor (green grass/leaves, apple, almond, aromatic herbs, chicory/rocket, and green almond) and taste characteristics (sweet or astringent) of oil was utilized. Further, the complexity, harmony, and persistence of the oils investigated were assessed using a 10-point overall structured rating scale from 0 (the lowest quality) to 10 (the highest quality).

2.7. Statistical Data Analysis

Statistical analysis of the data was performed using TIBCO Statistica Software Inc. v. 13.5.0 [52]. Morphological characteristics of the fruit, yield per tree, *B. oleae* fruit infestation, and olive quality and composition parameters were groups of data that were statistically processed by a two-way analysis of variance (ANOVA). Significant differences were further investigated used post hoc testing (Tukey HSD).

3. Results and Discussion

3.1. The Influence of Irrigation Treatment and Location on the Olive Fruit Fly Catch and the Proportion of Fruit Infected with the Olive Fruit Fly in the Harvest

There was a significant difference in the total captures across time and according to sex (Table 5). In 2020, significantly more individuals were counted on yellow plates; proportionally, the percentage of fruit infestation was higher. Other authors also agreed that in the coastal area of Zadar [53] and, more broadly, Dalmatia [28], meteorological conditions during autumn (September–October) had the greatest influence on the appearance of individuals and the height of catches on yellow sticky plates.

Table 5. Total catch of individuals, i.e., males and females separately on yellow plates, on fruits infected by olive fruit fly in the harvest of the cultivar Coratina upon different irrigation treatments (C, T_1, T_2, and T_3) in two locations (Žman, Novigrad), in 2020 and 2021.

No. Individuals	Year	Treatments (T)				Locations (L)		T	L	T × L
		C	T_1	T_2	T_3	Žman	Novigrad	*p*	*p*	*p*
Male and female	2020	82.29 ± 14.35 [a]	52.25 ± 9.28 [b]	50.38 ± 9.32 [b]	56.33 ± 10.10 [b]	98.02 ± 7.53 [a]	22.6 ± 2.75 [b]	*	***	n.s.
	2021	5.41 ± 1.55	4.62 ± 1.17	4.33 ± 1.10	3.87 ± 1.00	8.31± 0.91 [a]	0.81 ± 0.22 [b]	n.s.	***	n.s.
Male	2020	60.20 ± 11.26 [a]	33.33 ± 6.01 [b]	35.50 ± 7.57 [b]	35.62 ± 6.90 [b]	67.81 ± 6.01 [a]	14.52 ± 1.83 [b]	**	***	n.s.
	2021	2.91 ± 0.84	2.41 ± 0.63	2.58 ± 0.72	1.83 ± 0.59	4.47 ± 0.55 [a]	0.39 ± 0.11 [b]	n.s.	***	n.s.
Female	2020	22.08 ± 333	18.91± 667	14.87± 500	20.70± 8.33	30.20 ± 2.11 [a]	8.08 ± 1.06 [b]	n.s.	***	n.s.
	2021	2.50 ± 0.73	2.20 ± 0.62	1.75 ± 0.44	2.04 ± 0.51	3.83 ± 0.44 [a]	0.41 ± 0.13 [b]	n.s.	***	n.s.
% infected fruit	2020	3.67 ± 0.82 [b]	11.67 ± 1.74 [a]	11.42 ± 1.79 [a]	13.08 ± 3.05 [a]	14.54 ± 1.65 [a]	5.38 ± 0.71 [b]	***	***	*
	2021	0.67 ± 0.31	1.67 ± 0.47	1.50 ± 0.45	1.25 ± 0.46	2.21 ± 0.29 [a]	0.33 ± 0.17 [b]	n.s.	***	n.s.

Results are presented as means ± standard errors (n = 100). Lowercase letters represent statistically significant differences between mean values for each main factor $p \leq 0.05$ obtained by two-way analysis of variance and the reverse Tukey test. First-order interactions (T × L.) are shown, with significance: n.s., not significant; ***, $p \leq 0.001$; **, $p \leq 0.01$; *, $p \leq 0.05$. Treatments: C, rainfed conditions; T_1, deficit irrigation (the usual producer's practice); T_2, deficit irrigation acquired by SAN technology in respect to phenological stages; T_3, irrigation with 100% of evapotranspiration (ETc) level. Male + Female, average total capture of adult olive flies; Male, average capture of male adult olive flies; Female, average capture of female adult olive flies; % infected fruit, proportion of infected olive fruits at the time of harvest per 100 sampled fruits.

In 2021, the catch of adult olive flies was several times lower in total and separated by gender as compared to the 2020 findings. These data are contradictory because when measuring precipitation during 2021 in August and September, more of it was recorded than in 2020 in the same period. However, specifically in 2020, more summer moisture accumulated in July than in average years, so 80 mm fell in July in Žman and almost twice as much (170 mm) in Novigrad. Overall, more males were caught than females. This fact should also explain why the total number of adults in the non-irrigated treatment was significantly higher and the proportion of fruit infestation significantly lower than in the irrigated treatments. Therefore, regardless of the total number of adults caught on yellow plates, the non-irrigated treatment had the lowest proportion of infected fruit compared to the irrigated treatments, which in 2020 did not differ from each other. Overall, in no year was there a difference between the irrigated treatments in catches on yellow plates or the proportion of fruit infestation. However, in 2020, when there was more precipitation in total, and during July, the proportion of fruit infestation was significantly higher in irrigated than in non-irrigated treatments. Fewer captured females compared to males in these treatments caused a higher proportion of fruit infestation compared to the non-irrigated treatment (C). According to Bjeliš et al. [54], there was a significantly higher intensity of fruit infection by the olive fruit fly in irrigated treatments. Quesada-Moraga et al. [33] explained this connection of olive fruit fly infestation with irrigation in a more complex way. According to these authors, the increased presence of olive fruit fly adults in irrigated plots can be attributed to different environmental factors (lower temperature and higher relative humidity). These findings were corroborated by the work of Marchi et al. [32]. On the other hand, Quesada-Moraga et al. [33] found that some fruit variables such as diameter and oil yield can partially explain the sensitivity of oil and table olive cultivars to the olive fruit fly. Our obtained results partially corroborate theirs because during 2020, when different values of fruit width were measured, and the levels of oil yield in dry matter were at higher levels, the proportion of fruit infestation was also which is shown in the following Sections 3.2 and 3.3. These results are similar to those of Bjeliš et al. [54] and Quesada-Moraga et al. [33] in that irrigated treatments have a higher fruit infection, but this is valid only when the conditions for infection are present, i.e., when there is a high number of adults.

Differences in the total and separate number of adults by sex on yellow plates and the proportion of infected fruits were recorded in all years; these values were always higher at the Žman location. The primary reason may be the colder conditions experienced the winter, which affect the wintering of the species. In comparison with the Novigrad location, it is a moderately warm, humid climate with hot summers [37]. With respect to altitude, which is lower on Žman, the results are in agreement with Kounatidis et al. [55] who concluded that during autumn, "hot spots" of higher populations of olive fruit fly individuals exist at lower altitudes and "cold spots" at higher altitudes. And finally, these results may also be due to the abundance of olive groves in the landscape, as confirmed by Ortega et al. [56], where the conditions of Dugi Otok are higher than in Novigrad. Volakakis et al. [57] also pointed out that potential future changes in environmental conditions (higher summer temperatures; irregular and longer rainy periods in spring) and land use (larger number of abandoned orchards) should be taken into account when applying olive fruit fly control measures. The ongoing climate change will lead to a decrease in the area suitable for olive fruit fly in the future, as predicted by Gratsea et al. [58] for other olive-growing areas in Europe. However, this could be mitigated by a warmer spring or the possibility that the olive fruit fly ends its development cycle earlier and causes infestation before the summer heat [58].

The irrigated treatments (T_1, T_2, and T_3) in the year with a higher population of the olive fruit fly showed a difference in the proportion of fruit infestation but not among each other. Irrigation can be considered as a measure to control the olive fruit fly [33,57]. In agreement with our research, the optimal rations, i.e., in our case, the manufacturer's practice (T_1) and SAN technology (T_2), will sooner become established practices rather than adding water at the level of 100% evapotranspiration (T_3). The obtained results suggest that in years of high olive fruit fly flight, a great plant protection effort should be devoted to the prevention and protection of fruits that are irrigated in order to obtain high-quality oil.

3.2. The Influence of Irrigation and Location on the Morphological Characteristics of the Fruit

The morphological characteristics of the olive fruit of the cultivar Coratina according to irrigation variants (T) and locations (L) are shown in Table 6. They are largely in accordance with the morphological characteristics reported by Barranco et al. [41]. A lower category of fruit and stone mass was recorded only in the control treatment (C) in 2021, which was partly expected because that treatment was not irrigated (Table 6).

Table 6. Morphological characteristics of the fruit during harvest of the Coratina olive cultivar grown in different irrigation treatments (C, T_1, T_2, and T_3) at two locations (Žman, Novigrad) during the growing seasons of 2020 and 2021.

Parameter	Year	Treatment (T)				Location (L)		T	L	T x L
		C	T_1	T_2	T_3	Žman	Novigrad	p	p	p
Fruit weight (g)	2020	2.22 ± 0.03 ^{c}	2.92 ± 0.04 ^{a}	2.76 ± 0.04 ^{b}	2.89 ± 0.03 ^{a}	2.43 ± 0.01 ^{b}	2.97 ± 0.03 ^{a}	***	*	***
	2021	1.46 ± 0.02 ^{d}	2.34 ± 0.03 ^{c}	2.54 ± 0.03 ^{b}	2.86 ± 0.03 ^{a}	2.27 ± 0.02 ^{b}	2.34 ± 0.03 ^{a}	***	**	***
Fruit length (mm)	2020	20.43 ± 0.09 ^{c}	22.39 ± 0.14 ^{a}	21.93 ± 0.11 ^{b}	22.07 ± 0.09 ^{ab}	20.60 ± 0.05 ^{b}	22.81 ± 0.09 ^{a}	***	***	***
	2021	16.77 ± 0.11 ^{d}	19.51 ± 0.08 ^{c}	20.2 ± 0.08 ^{b}	21.27 ± 0.10 ^{a}	18.84 ± 0.08 ^{b}	20.03 ± 0.09 ^{a}	***	***	***
Fruit width (mm)	2020	13.53 ± 0.07 ^{c}	15.11 ± 0.08 ^{a}	14.63 ± 0.07 ^{b}	14.93 ± 0.06 ^{a}	14.02 ± 0.04 ^{b}	15.07 ± 0.06 ^{a}	***	***	***
	2021	14.83 ± 2.88	14.41 ± 0.22	14.49 ± 0.05	15.15 ± 0.07	13.98 ± 0.05	15.46 ± 1.44	n.s.	n.s.	n.s.
Stone weight (g)	2020	0.57 ± 0.01 ^{b}	0.63 ± 0.01 ^{a}	0.61 ± 0.01 ^{a}	0.62 ± 0.01 ^{a}	0.69 ± 0.00 ^{a}	0.52 ± 0.00 ^{b}	***	***	***
	2021	0.42 ± 0.01 ^{d}	0.54 ± 0.00 ^{c}	0.58 ± 0.01 ^{b}	0.61 ± 0.01 ^{a}	0.52 ± 0.00 ^{b}	0.55 ± 0.00 ^{a}	***	***	**
Stone length (mm)	2020	16.05 ± 0.08 ^{c}	16.29 ± 0.06 ^{b}	16.40 ± 0.07 ^{b}	16.66 ± 0.07 ^{a}	16.33 ± 0.04	16.37 ± 0.05	***	n.s.	***
	2021	13.37 ± 0.12 ^{d}	14.85 ± 0.07 ^{c}	15.50 ± 0.07 ^{b}	16.06 ± 0.08 ^{a}	14.17 ± 0.06 ^{b}	15.72 ± 0.07 ^{a}	***	***	***
Stone width (mm)	2020	7.40 ± 0.04 ^{b}	7.65 ± 0.03 ^{a}	7.62 ± 0.03 ^{a}	7.58 ± 0.03 ^{a}	8.05 ± 0.02 ^{a}	7.08 ± 0.02 ^{b}	***	***	***
	2021	7.22 ± 0.15 ^{b}	7.57 ± 0.03 ^{a}	7.64 ± 0.03 ^{a}	7.75 ± 0.02 ^{a}	7.57 ± 0.02	7.52 ± 0.08	***	n.s.	n.s.
Pulp mass (g)	2020	1.65 ± 0.02 ^{b}	2.30 ± 0.04 ^{a}	2.15 ± 0.03 ^{a}	2.27 ± 0.03 ^{a}	1.74 ± 0.01 ^{b}	2.45 ± 0.03 ^{a}	***	***	***
	2021	1.04 ± 0.02 ^{d}	1.80 ± 0.02 ^{c}	1.97 ± 0.02 ^{b}	2.25 ± 0.03 ^{a}	1.74 ± 0.02	1.79 ± 0.02	***	n.s.	***
Pulp ratio (%)	2020	73.88 ± 0.28 ^{c}	77.12 ± 0.33 ^{a}	76.85 ± 0.29 ^{b}	77.86 ± 0.24 ^{a}	71.24 ± 0.13 ^{b}	81.61 ± 0.11 ^{a}	***	***	***
	2021	69.89 ± 0.42 ^{d}	76.45 ± 0.21 ^{c}	77.05 ± 0.15 ^{b}	78.05 ± 0.16 ^{a}	75.64 ± 0.24 ^{a}	75.08 ± 0.18 ^{b}	***	*	***

Results are presented as means ± standard errors (n = 40). Lowercase letters represent statistically significant differences between mean values for each main factor $p \leq 0.05$ obtained by two-way analysis of variance and the reverse Tukey test. First-order interactions (T × L.) are shown, with significance: n.s., not significant; ***, $p \leq 0.001$; **, $p \leq 0.01$; *, $p \leq 0.05$. Treatments: C, rainfed conditions; T_1, deficit irrigation (the usual producer's practice); T_2, deficit irrigation acquired by SAN technology in respect to phenological stages; T_3, irrigation with 100% of evapotranspiration (ETc) level.

Both main factors, namely irrigation practices and location, influenced the morphological characteristics of the fruit, with an interaction noted between them (Table 6). Thus, all irrigation treatments had a positive effect on all measured morphological characteristics of the fruit in both years of the study. The highest fruit weight was found in treatments T_1 (2.92 ± 0.04) and T_3 (2.89 ± 0.03) in 2020 and T_3 (2.86 ± 0.03) in 2021. Almost the same trend was recorded in both years for other measured parameters such as length, width of fruit and stone, pulp mass, and the ratio of pulp mass to stone mass (Table 6). The results were in accordance with other research that found that increasing the amount of irrigation water had a positive effect on the morphological characteristics of the fruit [59–62]. During drought, the water content in the plant decreases, the cells shrink, and the cell wall relaxes, resulting in a loss of turgor. All this results in a reduction of the water potential in the leaves and fruits, which affects cell division and expansion. Lack of water during fruit development affects leaf photosynthesis and a number of other physiological functions, resulting in smaller fruit [63]. Smaller differences between the irrigated treatments were found in 2020, when a higher amount of precipitation was recorded in July (Figure 1). This finding is supported by Jukić Špika et al. [62], who found a greater influence of irrigation in 2017, when a lower amount of precipitation was recorded during the time of stone hardening and intense fruit growth compared to 2016 with higher amounts of precipitation.

Patumi et al. [64] determined that there are different responses of olives to the volume of irrigation water, especially in the period from 1997–1998. when there was a higher amount of precipitation during the summer period.

From the technological aspect of EVOO production, the mesocarp (pulp) is an important part of the fruit because over 90% of the oil is extracted from it [6], which is also positively affected by irrigation. The location also had a significant influence on the characteristics of the fruit, where the values of most observed properties were higher in Novigrad compared to Žman (Table 6). The results were consistent with other studies that showed that increasing the amount of irrigation water has a positive effect on fruit and stone weight [59,62]. Freihat [61] found that irrigation of 40, 60, and 80 L on a weekly basis had a significant effect on the weight of fruits produced by both olive varieties 'Grossa de Spain' and Nabali in both consecutive growing seasons (2014 and 2015). The effect is particularly visible when both cultivars received 80 L of water on a weekly basis, which was the highest amount of water in that study, overlapping with the results obtained in this study with the T_3 treatment. Several studies have found that location-specific pedoclimatic conditions significantly affect the growth and development of the olive fruit [22,65]. In fact, in this study, as stated, we dealt with two climatically different locations, and the assumption is that the drier and warmer climate at the Žman location affected slightly weaker growth and fruit development. In addition, it is predicted that higher temperatures in the context of climate change will have an increasingly negative impact on the growth and development of fruit and thus the fruit yield [22]. Therefore, the higher temperature in the island climate reduces the effect of irrigation by increasing evapotranspiration, which causes a certain impact on fruit morphology. Abiotic stress, including higher temperature, causes numerous changes that are also visible in the morphological parameters of the fruit [65,66]. The location of Žman is warmer compared to Novigrad, which could partly have influenced the results obtained.

Treatment T_3, in which the highest amount of irrigation water was added in 2021, gave better results for fruit weight, pulp mass, and pulp ratio compared to the other two treatments (T_1 and T_2), but such a result was not found in the previous year, 2020, when these differences between treatments were not significant. Therefore, from the point of view of the conservation and rational management of irrigation water, it is justified to follow the production practice (T_1), which is acquired through many years of experience of the producer in production, but it is also justified to use SAN technology (T_2), which uses less water for irrigation. The results showed that these practices could significantly reduce the use of irrigation water with minimal negative impacts on the morphological characteristics of the fruit.

3.3. Influence of Irrigation and Location on Fruit Yield per Tree and Oil and Moisture Content in Olive Paste

Table 7 shows the fruit yield per tree, oil yield, dry matter, moisture, oil on dry mass, and oil on fresh mass for 2020 and 2021. In both investigated years, the yield per olive tree did not differ statistically significantly according to irrigation treatments, while a difference was recorded by location.

The results were similar to those by Pierantozzi et al. [60], who found that irrigation had a slight effect on the yield of olive fruit per tree, as also measured by Jukić Špika et al. [62] on meliorated karst on the cultivar Oblica. In contrast, Nuzzo et al. [67] found differences in yield between irrigated and non-irrigated trees of the Coratina cultivar in the first four years after planting. Irrigation has a greater impact on olive fruit yield when it is carried out before flowering because it more greatly affects the formation of flowers and fruit set than when it is carried out after fruit set during the summer period [68]. This was confirmed by Quan et al. [69] in southwestern China on the olive cultivars Coratina and Koroneiki. Therefore, we can attribute the lack of influence of irrigation on fruit yield to one part and the period in which it was carried out. In 2020, the fruit yield per olive tree was higher in Novigrad (Table 7), while the reverse was found in 2021. This can be partly attributed to alternative bearing to which the olive is prone as a perennial crop [70]. In addition, the occurrence of alternative bearing is also related to external factors, which may be the reason for the differences found between the two locations investigated by Kour et al. [71]. Sastre et al. [72] found differences in yield between locations and years of cultivation, while irrigation did not affect fruit yield. In our study in 2020, in all irrigated treatments, the oil yield was higher compared to the control treatment (C), while such a trend was recorded only in the T_3 treatment in 2021. The year and weather conditions partly affect the oil content [73,74]. In 2020, a greater amount of precipitation fell in July compared to 2021, which could partly affect this result. Similarly, the proportion of oil in the olive paste was higher in the irrigated cultivars in 2020, while in 2021, this was recorded only for the T_3 treatment, while the proportion of oil in dry matter and the proportion of oil based on fresh mass was higher than the control (C) in all treatments (T_1, T_2, and T_3) in 2020, and they did not differ statistically (Table 7). In 2021, the proportions of oil in fresh paste in treatments T_1 and T_2 and T_3 were higher compared to control treatments (C), while at the same time, no difference was recorded between T_1 and T_2 or between T_2 and T_3; in addition, treatments T_1 and T_2 did not differ statistically significantly (Table 7). Environmental conditions have a great influence on oil accumulation and the final amount of oil. Navas-Lopez et al. [75] found that the accumulation of time depends on environmental conditions, and PLS (partial least square) analysis suggests that temperature is one of the main factors affecting oil accumulation.

Table 7. Fruit yield per tree, oil yield, dry matter, moisture, oil on dry mass, and oil on fresh mass during the production of virgin olive oils from Coratina olives grown in different irrigation treatments (C, T_1, T_2, and T_3) on two locations (Žman, Novigrad) during the growing seasons of 2020 and 2021.

Factors	Year	Treatments (T)				Locations (L)		T	L	T × L
		C	T_1	T_2	T_3	Žman	Novigrad	p	p	p
Fruit yield per tree (kg/tree) $^+$	2020	11.22 ± 3.31	10.55 ± 1.4	10.77 ± 2.83	11.49 ± 2.19	6.62 ± 0.44 ^{b}	15.40 ± 1.47 ^{a}	n.s.	***	n.s.
	2021	4.62 ± 1.79	6.29 ± 1.36	5.05 ± 1.73	7.10 ± 1.58	7.24 ± 1.04 ^{a}	4.29 ± 1.05 ^{b}	n.s.	n.s.	n.s.
Oil yield (%)	2020	6.51 ± 0.45 ^{b}	10.07 ± 0.64 ^{a}	10.05 ± 0.35 ^{a}	10.26 ± 0.17 ^{a}	8.46 ± 0.53 ^{b}	9.99 ± 0.48 ^{a}	***	***	**
	2021	8.05 ± 0.45 ^{b}	8.45 ± 0.26 ^{b}	7.89 ± 0.81 ^{b}	9.95 ± 0.19 ^{a}	8.77 ± 0.31 ^{a}	8.40 ± 0.49 ^{b}	***	n.s.	**
Dry matter (%)	2020	41.88 ± 0.59	42.50 ± 0.79	42.44 ± 1.17	42.06 ± 1.21	44.13 ± 0.32 ^{a}	40.31 ± 0.34 ^{b}	n.s.	***	*
	2021	45.89 ± 1.54	45.34 ± 1.17	47.42 ± 1.42	45.13 ± 1.08	43.28 ± 0.42 ^{b}	48.61 ± 0.51 ^{a}	n.s.	***	n.s.
Moisture (%)	2020	58.12 ± 0.59	57.50 ± 0.79	57.56 ± 1.17	57.94 ± 1.21	55.87 ± 0.32 ^{b}	59.69 ± 0.34 ^{a}	n.s.	***	*
	2021	54.11 ± 1.54	54.66 ± 1.17	52.58 ± 1.42	54.87 ± 1.08	56.72 ± 0.42 ^{a}	51.39 ± 0.51 ^{b}	n.s.	***	n.s.
Oil on dry weight basis (%)	2020	30.64 ± 1.73 ^{b}	39.86 ± 1.1 ^{a}	39.04 ± 1.18 ^{a}	40.08 ± 0.58 ^{a}	35.05 ± 1.44 ^{b}	39.76 ± 1.03 ^{a}	***	***	n.s.
	2021	29.04 ± 0.79 ^{c}	32.90 ± 1.31 ^{b}	35.00 ± 0.38 ^{ab}	35.53 ± 0.51 ^{a}	33.73 ± 0.92 ^{a}	32.51 ± 0.94 ^{b}	***	*	**
Oil on fresh weight basis (%)	2020	17.85 ± 1.16 ^{b}	22.96 ± 0.92 ^{a}	22.54 ± 1.10 ^{a}	23.26 ± 0.8 ^{a}	19.56 ± 0.76 ^{b}	23.74 ± 0.66 ^{a}	***	***	n.s.
	2021	16.39 ± 0.71 ^{c}	18.05 ± 1.07 ^{b}	18.40 ± 0.54 ^{b}	19.48 ± 0.35 ^{a}	19.46 ± 0.30 ^{a}	16.7 0± 0.51 ^{b}	***	***	***

Results are presented as means ± standard errors (n^+ = 12; n = 3). Lowercase letters represent statistically significant differences between mean values for each main factor $p \leq 0.05$ obtained by two-way analysis of variance and the reverse Tukey test. First-order interactions (T × L.) are shown, with significance: n.s., not significant; ***, $p \leq 0.001$; **, $p \leq 0.01$; *, $p \leq 0.05$. Treatments: C, rainfed conditions; T_1, deficit irrigation (the usual producer's practice); T_2, deficit irrigation acquired by SAN technology in respect to phenological stages; T_3, irrigation with 100% of evapotranspiration (ETc) level.

Irrigation treatments did not affect the yield of olives but significantly affected the increased oil content differently depending on the year. The expected occurrences of extreme conditions, especially for the Mediterranean area, and the different responses of olives to them as well as the obtained results can confirm this.

3.4. Influence of Irrigation and Location on Oil Quality

The analytical parameters of olive oil quality are shown in Table 8. PV ranged from 0.96 to 1.80 meq O_2/kg, FFA from 0.11 to 0.27%, K_{232} from 1.84 to 0.27, and K_{270} from

0.16 to 0.19, while Δ K was less than 0.01 (Table 8). Based on these parameter values, all investigated oils fell into the EVOO category (Commission Delegated Regulation (EU) 2022/2104, 2022) [47]. This category of oil is the most valued among consumers due to its valuable sensory and nutritional properties and proven positive effect on human health [7,8,76,77].

Table 8. Peroxide value (PV), proportion of free fatty acids (FFA), spectrophotometric extinction coefficient (K_{232}, K_{270}, and Δ K), from the Coratina cv. olive grown in different irrigation treatments (C, T_1, T_2, and T_3) at two locations (Žman, Novigrad) during the growing seasons of 2020 and 2021.

Factors Parameters	Year	Treatments (T)				Locations (L)		T	L	T × L
		C	T_1	T_2	T_3	Žman	Novigrad	*p*	*p*	*p*
PV (meq O_2/kg)	2020	1.80 ± 0.19 ^{a}	1.18 ± 0.17 ^{b}	1.08 ± 0.06 ^{bc}	1.03 ± 0.02 ^{c}	1.51 ± 0.14 ^{a}	1.03 ± 0.07 ^{b}	***	***	***
	2021	1.08 ± 0.02 ^{ab}	1.20 ± 0.10 ^{a}	1.10 ± 0.06 ^{ab}	0.96 ± 0.07 ^{b}	1.21 ± 0.04 ^{a}	0.96 ± 0.04 ^{b}	***	***	*
FFA (%)	2020	0.15 ± 0.02 ^{ab}	0.16 ± 0.02 ^{a}	0.14 ± 0.02 ^{bc}	0.14 ± 0.02 ^{c}	0.19 ± 0.00 ^{a}	0.11 ± 0.00 ^{b}	***	***	n.s.
	2021	0.25 ± 0.01	0.27 ± 0.01	0.27 ± 0.01	0.25 ± 0.01	0.25 ± 0.01 ^{b}	0.27 ± 0.01 ^{a}	n.s.	*	n.s.
K_{232}	2020	1.88 ± 0.02	1.90 ± 0.06	1.91 ± 0.06	1.99 ± 0.04	2.00 ± 0.02 ^{a}	1.84 ± 0.03 ^{b}	n.s.	***	*
	2021	2.05 ± 0.03	2.04 ± 0.02	2.02 ± 0.02	2.02 ± 0.06	2.03 ± 0.02	2.03 ± 0.02	n.s.	n.s.	**
K_{270}	2020	0.17 ± 0.00	0.17 ± 0.01	0.17 ± 0.01	0.17 ± 0.01	0.19 ± 0.00 ^{a}	0.16 ± 0.00 ^{b}	n.s.	***	*
	2021	0.19 ± 0.00	0.19 ± 0.00	0.19 ± 0.00	0.19 ± 0.00	0.19 ± 0.00	0.19 ± 0.00	n.s.	n.s.	**
ΔK	2020	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	n.s.	n.s.	n.s.
	2021	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	n.s.	n.s.	n.s.

Results are presented as means ± standard errors (n = 3). Lowercase letters represent statistically significant differences between mean values for each main factor $p \leq 0.05$ obtained by two-way analysis of variance and the reverse Tukey test. First-order interactions (T × L.) are shown, with significance: n.s., not significant; ***, $p \leq 0.001$; **, $p \leq 0.01$; *, $p \leq 0.05$. Treatments: C, rainfed conditions; T_1, deficit irrigation (the usual producer's practice); T_2, deficit irrigation acquired by SAN technology in respect to phenological stages; T_3, irrigation with 100% of evapotranspiration (ETc) level.

The value of oxidative changes in olive oil (PV) in both years and hydrolytic changes (FFA) in 2021 showed a slight decrease with the addition of higher amounts of irrigation water (Table 8). This change was from 1.80 on C to 1.03 on T_3 and did not affect the change of olive oil category according to the Commission Regulation [47]. A change in the category of virgin olive oil can affect economic losses for the producer [77]. Jukić Špika et al. [62] found a similar trend for the cultivar Oblica grown on reclaimed karst for FFA parameters. Naima FFA had the lowest values in the treatment (Irr 100%), in which the highest amount of irrigation water was added during two years, while in one year, there was no difference between treatments. At the same time, Jukić Špika et al. [62] did not find a clear trend in the influence of irrigation on PV. Other studies showed different patterns of the influence of irrigation on these parameters. For example, Dag et al. [78] found that an increase in irrigation increased FFA, while PV was unaffected. Bedbabis et al. [79] found that irrigation only affected the extinction coefficient (K_{232} and K_{270}), while it did not affect FFA and PV. Caruso et al. [80] found a slight influence of irrigation on FFA and PV, whereas Sánchez-Rodríguez et al. [81] found no influence. Possible reasons for the contradictory results in this research and the literature may be that only healthy fruits processed within 24 h were used, and the FFA value is a quality parameter related to hydrolytic changes and fruit damage, and the PV parameter is related to oxidative changes.

3.5. Influence of Irrigation and Location on Phenoic Compounds

Table 9 details the phenolic profile of Coratina cv. EVOO grown in different irrigation treatments (C, T_1, T_2, and T_3) at the two research locations (Žman, Novigrad). The content of total simple phenols differed in all treatments (C, T_1, T_2, and T_3); the highest was in treatment T_3 in 2020, and in 2021, it was highest in treatments T_2 and T_3.

Table 9. Phenolic profile of olive oil of the cultivar Coratina cv. grown in different irrigation treatments (C, T_1, T_2, and T_3) at two locations (Žman, Novigrad) during the growing seasons of 2020 and 2021.

Factors Phenolic	Year	Treatments (T)				Locations (L)		T	L	T × L
		C	T_1	T_2	T_3	Žman	Novigrad	p	p	p
Simple phenols										
Hydroxytyrosol	2020	2.56 ± 0.21 ^{d}	4.19 ± 0.27 ^{c}	5.82 ± 0.26 ^{b}	6.89 ± 0.44 ^{a}	5.20 ± 0.62 ^{a}	4.53 ± 0.42 ^{b}	***	*	n.s.
	2021	9.28 ± 2.74 ^{b}	7.00 ± 1.04 ^{c}	9.12 ± 2.01 ^{b}	10.34 ± 1.30 ^{a}	8.66 ± 1.44 ^{b}	9.21 ± 1.19 ^{a}	***	**	***
Tyrosol	2020	5.09 ± 0.42 ^{d}	8.67 ± 0.32 ^{c}	10.66 ± 0.50 ^{b}	12.70 ± 0.57 ^{a}	9.99 ± 0.93 ^{a}	8.56 ± 0.82 ^{b}	***	***	n.s.
	2021	10.87 ± 1.93 ^{b}	9.83 ± 1.27 ^{b}	14.12 ± 1.90 ^{a}	14.15 ± 1.72 ^{a}	12.49 ± 1.72	12.00 ± 0.66	***	n.s.	***
Vanillin	2020	0.16 ± 0.03 ^{a}	0.13 ± 0.01 ^{ab}	0.14 ± 0.01 ^{ab}	0.12 ± 0.01 ^{b}	0.16 ± 0.01 ^{a}	0.11 ± 0.01 ^{b}	**	***	***
	2021	0.22 ± 0.03 ^{a}	0.15 ± 0.01 ^{b}	0.11 ± 0.00 ^{c}	0.12 ± 0.00 ^{c}	017 ± 0.02 ^{a}	0.13 ± 0.01 ^{b}	***	***	***
Hydroxytyrosol acetate	2020	0.12 ± 0.01	0.13 ± 0.02	0.11 ± 0.02	0.09 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	n.s.	n.s.	n.s.
	2021	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	n.s.	n.s.	n.s.
Total simple phenols	2020	7.92 ± 0.55 ^{d}	13.12 ± 0.58 ^{c}	16.74 ± 0.66 ^{b}	19.79 ± 0.99 ^{a}	15.46 ± 1.53 ^{a}	13.32 ± 1.21 ^{b}	***	***	n.s.
	2021	20.38 ± 4.63 ^{b}	16.98 ± 2.3 ^{c}	23.35 ± 3.91 ^{a}	24.61 ± 3.02 ^{a}	21.31 ± 3.14	21.34 ± 1.83	***	n.s.	***
Phenolic acids										
Vanillic acid	2020	3.89 ± 0.52	3.26 ± 0.31	3.69 ± 0.52	3.46 ± 0.47	2.65 ± 0.14 ^{b}	4.50 ± 0.18 ^{a}	n.s.	***	n.s.
	2021	0.37 ± 0.03 ^{b}	0.47 ± 0.03 ^{a}	0.31 ± 0.07 ^{b}	0.40 ± 0.05 ^{ab}	0.47 ± 0.02 ^{a}	0.30 ± 0.03 ^{b}	**	***	n.s.
p-Coumaric acid	2020	1.66 ± 0.25 ^{a}	1.40 ± 0.10 ^{b}	1.40 ± 0,05 ^{b}	1.42 ± 0.06 ^{b}	1.69 ± 0.09 ^{a}	1.24 ± 0.04 ^{b}	*	*	***
	2021	0.90 ± 0.09 ^{a}	0.86 ± 0.07 ^{b}	0.69 ± 0.04 ^{b}	0.85 ± 0.07 ^{b}	0.73 ± 0.03 ^{b}	0.92 ± 0.06 ^{a}	**	***	**
Total phenolic acids	2020	5.55 ± 0.41	4.66 ± 0.24	5.09 ± 0.49	4.88 ± 0.43	4.35 ± 0.2 ^{b}	5.74 ± 0.20 ^{a}	n.s.	***	n.s.
	2021	1.27 ± 0.07 ^{a}	1.34 ± 0.05 ^{a}	1.00 ± 0.10 ^{b}	1.25 ± 0.06 ^{a}	1.21 ± 0.03	1.22 ± 0.08	***	n.s.	***
Flavonoids										
Luteolin	2020	2.12 ± 0.17	2.18 ± 0.33	2.01 ± 0.39	2.02 ± 0.34	1.46 ± 0.07 ^{b}	2.69 ± 0.14 ^{a}	n.s.	***	n.s.
	2021	1.28 ± 0.05 ^{b}	1.70 ± 0.11 ^{b}	1.22 ± 0.17 ^{a}	1.32 ± 0.09 ^{b}	1.44 ± 0.09	1.32 ± 0.10	**	n.s.	**
Apigenin	2020	0.35 ± 0.03	0.32 ± 0.05	0.31 ± 0.07	0.31 ± 0.06	0.22 ± 0.01 ^{b}	0.43 ± 0.02 ^{a}	n.s.	***	n.s.
	2021	0.16 ± 0.02 ^{b}	0.22 ± 0.01 ^{a}	0.13 ± 0.01 ^{b}	0.16 ± 0.01 ^{b}	0.16 ± 0.01 ^{b}	0.18 ± 0.01 ^{a}	***	**	***
Total flavonoids	2020	2.47 ± 0.2	2.49 ± 0.38	2.32 ± 0.46	2.33 ± 0.41	1.68 ± 0.09 ^{b}	3.12 ± 0.16 ^{a}	n.s.	***	n.s.
	2021	1.43 ± 0.06 ^{b}	1.92 ± 0.12 ^{a}	1.35 ± 0.18 ^{b}	1.48 ± 0.10 ^{b}	1.60 ± 0.10	1.50 ± 0.11	**	n.s.	***
Lignans										
Pinoresinol	2020	3.52 ± 0.47 ^{ab}	3.27 ± 0.12 ^{b}	4.22 ± 0.21 ^{a}	4.14 ± 0.25 ^{a}	3.99 ± 0.19 ^{a}	3.58 ± 0.25 ^{b}	**	*	**
	2021	6.60 ± 1.47 ^{b}	6.99 ± 1.40 ^{b}	9.05 ± 0.82 ^{a}	8.80 ± 0.16 ^{a}	6.70 ± 0.97 ^{b}	9.02 ± 0.35 ^{a}	***	***	***
Acetoxypinoresinol	2020	19.62 ± 0.90	16.62 ± 0.64	18.94 ± 1.38	17.48 ± 0.93	17.10 ± 0.61 ^{b}	19.23 ± 0.76 ^{a}	n.s.	*	*
	2021	18.56 ± 0.66 ^{a}	19.35 ± 1.11 ^{a}	15.04 ± 2.44 ^{b}	15.72 ± 0.67 ^{b}	19.10 ± 0.74 ^{b}	15.23 ± 1.10 ^{a}	***	***	***
Total lignans	2020	/	/	/	/	/	/	/	/	/
	2021	25.16 ± 1.94	26.34 ± 0.63	24.09 ± 3.26	24.51 ± 0.76	25.8 ± 1.21 ^{a}	24.25 ± 1.43 ^{b}	n.s.	*	***
Secoiridoids										
3,4-DHPEA-EDA	2020	204.54 ± 25.86 ^{a}	148.41 ± 9.29 ^{b}	154.05 ± 6.54 ^{b}	139.24 ± 11.89 ^{b}	178.08 ± 15.34 ^{a}	145.04 ± 6.76 ^{b}	***	**	***
	2021	293.89 ± 17.93 ^{a}	227.14 ± 10.84 ^{b}	147.58 ± 12.54 ^{d}	195.72 ± 5.92 ^{c}	235.55 ± 19.19 ^{a}	196.62 ± 14.81 ^{b}	***	***	***
Oleuropein aglycone (isomer I)	2020	332.43 ± 17.71	337.60 ± 30.13	318.95 ± 31.43	305.39 ± 29.60	370.95 ± 11.67 ^{a}	276.24 ± 13.63 ^{b}	n.s.	***	n.s.
	2021	361.55 ± 11.77 ^{a}	346.65 ± 5.55 ^{a}	279.48 ± 32.84 ^{b}	285.63 ± 6.10 ^{b}	340.41 ± 10.71 ^{a}	296.24 ± 18.09 ^{b}	***	***	***
p-HPEA-EDA	2020	175.98 ± 15.89	200.52 ± 9.58	200.68 ± 11.35	180.72 ± 9.86	200.10 ± 5.16 ^{a}	178.85 ± 10,27 ^{b}	n.s.	*	**
	2021	192.74 ± 19.86 ^{a}	156.66 ± 8.68 ^{b}	135.88 ± 6.21 ^{b}	135.04 ± 3.63 ^{b}	167.53 ± 13.29 ^{a}	142.63 ± 3.64 ^{b}	***	***	***
Oleuropein + ligstroside aglycones I and II	2020	189.7 ± 12.10 ^{b}	258.06 ± 21.83 ^{a}	250.38 ± 22.64 ^{a}	246.67 ± 18.7 ^{a}	266.84 ± 15.96 ^{a}	205.57 ± 6.79 ^{b}	**	***	*
	2021	70.39 ± 4.42 ^{c}	74.23 ± 1.96 ^{c}	202.46 ± 60.42 ^{a}	186.34 ± 53.03 ^{b}	73.55 ± 2.01 b	193.16 ± 38.78 a	***	***	***
Oleuropein aglycone (isomer II)	2020	37.86 ± 2.11	38.13 ± 2.16	41.29 ± 2.43	39.71 ± 3.19	43.44 ± 1.33 ^{a}	35.05 ± 1.05 ^{b}	n.s.	***	n.s.
	2021	88.46 ± 6.82 ^{a}	86.41 ± 8.73 ^{ab}	79.31 ± 4.99 ^{b}	66.87 ± 1.65 ^{c}	91.47 ± 4.81 ^{b}	69.06 ± 1.06 ^{a}	***	***	***
Ligstroside aglycone (isomer III)	2020	11.57 ± 0.54 ^{b}	15.94 ± 1.74 ^{a}	17.6 ± 1.70 ^{a}	17.77 ± 1.37 ^{a}	13.32 ± 0.57 ^{b}	18.12 ± 1.27 ^{a}	***	***	*
	2021	14.71 ± 1.05 ^{b}	18.18 ± 1.79 ^{a}	17.47 ± 2.08 ^{ab}	16.30 ± 0.65 ^{ab}	16.37 ± 1.15	16.96 ± 1.02	*	n.s.	***
Oleuropein aglycone (isomer III)	2020	16.37 ± 1.00 ^{b}	21.87 ± 0.76 ^{a}	24.64 ± 2.66 ^{a}	24.93 ± 2.74 ^{a}	24.79 ± 1.96 ^{a}	19.11 ± 0.73 ^{b}	***	***	***
	2021	45.20 ± 7.64 ^{b}	51.34 ± 6.83 ^{a}	40.64 ± 2.39 ^{c}	31.92 ± 1.32 ^{d}	51.54 ± 4.23 ^{a}	33.01 ± 1.10 ^{b}	***	***	***

Table 9. *Cont.*

Factors Phenolic	Year	Treatments (T)				Locations (L)		T	L	T × L
		C	T_1	T_2	T_3	Žman	Novigrad	*p*	*p*	*p*
Secoiridoids										
Total secoiridoids	2020	968.46 ± 60.7	1020.54 ± 44.38	1007.59 ± 68.63	954.43 ± 70.04	1097.52 ± 24.22 ^{a}	877.98 ± 28.76 ^{b}	n.s.	***	n.s.
	2021	1066.95 ± 61.36 ^{a}	960.62 ± 32.96 ^{b}	902.83 ± 13.79 ^{c}	917.81 ± 58.27 ^{bc}	976.42 ± 47.36 ^{a}	947.68 ± 19.63 ^{b}	***	*	***
Total phenolic content	2020	1007.53 ± 61.92	1060.70 ± 44.06	1054.89 ± 67.27	1003.06 ± 70.48	1140.10 ± 24.66 ^{a}	922.98 ± 29.09 ^{b}	***	***	n.s.
	2021	1115.19 ± 55.14 ^{a}	1007.20± 30.55 ^{b}	952.62 ± 12.21 ^{c}	969.66 ± 55.03 ^{bc}	1026.34 ± 43.91 ^{a}	995.99 ± 19.54 ^{b}	n.s.	***	***

Results are presented as means ± standard errors (n = 3). Lowercase letters represent statistically significant differences between mean values for each main factor $p \leq 0.05$ obtained by two-way analysis of variance and the reverse Tukey test. First-order interactions (T × L.) are shown, with significance: n.s., not significant; ***, $p \leq 0.001$; **, $p \leq 0.01$; *, $p \leq 0.05$. Treatments: C, rainfed conditions; T_1, deficit irrigation (the usual producer's practice); T_2, deficit irrigation acquired by SAN technology in respect to phenological stages; T_3, irrigation with 100% of evapotranspiration (ETc) level; 3,4-DHPEA-EDA, oleuropein-aglycone di-aldehyde; *p*-HPEA, ligstroside-aglycone di-aldehyde.

In 2020, the lowest values of simple phenols were found in treatment C, while in 2021, the lowest simple phenols were found in treatment T_1. From Žman in 2020, the total content of simple phenols was higher than at Novigrad, while in 2021, there was no difference between the research locations (Table 9).

In contrast to these findings, Faghim et al. [82] showed that irrigated trees had a lower content of total simple phenols, by almost 40%, compared to rainfed trees. The reason for such a sequence of results can be found in the unusually high amount of precipitation in July 2020 at Novigrad (Figure 1), where the precipitation evened out the content of total simple phenols by treatments. In 2021, when precipitation decreased, the content of total simple phenols increased threefold in the rainfed treatment.

Hydrotyrosol and tyrosol were highest in the T_3 treatment in both years except in 2021, when there was no difference in the contribution of tyrosol between the T_2 and T_3 treatments. Hydrotyrosol and tyrosol were higher at Žman in 2020, while hydrotyrosol was higher at Novigrad in 2021, and tyrosol did not differ between locations in 2021 (Table 9). However, Caruso et al. [80], in a study on the Frantoio cultivar, reported that the concentration of tyrosol was almost the same in all irrigation treatments, while the concentration of hydroxytyrosol differed over the years. In first year of the research, irrigation increased concentration, but the opposite was found in the second year. In the third year, the results were very low. Therefore, the influence of the cultivation area and the amount of water added did not have an effect on the values of hydrotyrosol and tyrosol. The same finding was shown by Faghim et al. [82].

Research on the Chemali cultivar by Faghim et al. [82] showed that tyrosol was higher in the rainfed treatment (10.65 ± 0.005 mg/kg^{-1}) and slightly lower in the irrigated treatment (9.52 ± 0.02 mg/kg^{-1}). Also, the content of hydroxytyrosol was more abundant in the rainfed treatment (13.42 ± 0.01 mg kg^{-1}) than in the irrigated treatment (5.35 ± 0.03 mg kg^{-1}) [79]. Since the research of Faghim et al. [82] used only two treatments, we can conclude that obtained results in the second year partially showed the opposite. The treatment with the rainfed (C) water source had the highest hydroxytyrosol values, followed by T_3. Similar trends can be associated with the hydrotyrosol values obtained in 2021, when only the T_1 treatment had a lower concentration of hydrotyrosol compared to the C treatment. Caruso at al. [80] reported for cultivar Fraintoio that there was no difference between treatments, which is in line with the results obtained. The reason for this trend can be found in the influence of various abiotic factors on the effect of irrigation. Since they are different at a certain microlocations, so are the results, even though the research factors are uniform.

Vanillin in 2020 differed neither between treatments C, T_1, and T_2 nor between T_1, T_2, and T_3, while in 2021, the highest contribution was confirmed in treatment C and the lowest in treatments T_2 and T_3. In both research years, vanillin was higher at the Žman location (Table 9). Vanillin content in the research of Sena-Moreno et al. [83] was the lowest in the treatment with optimal irrigation and the highest in the treatments of 20% and 15% of added water compared to the treatment with optimal irrigation. The above results coincide with the second year (2021) of our research. The climate of the research area in the study of Sena-Morano et al. [83] is categorized as Continental Mediterranean with the influence of the Atlantic Ocean, where the average annual precipitation is 469 mm. We have similar climatic conditions in Novigrad, where the average amount of precipitation is 853.9 mm [84], but it is more distributed in the autumn and winter months. Therefore, we can conclude that these are comparable micro-locations and the same annual climate conditions.

The content of total phenolic acids did not differ between treatments in 2020, while in 2021, the lowest value was confirmed in treatment T_2, and the other treatments, i.e., C, T_1, and T_3, did not significantly differ (Table 3). Differences in the content of total phenolic acids were recorded by research location (Žman, Novigrad) in 2020, while in 2021, no differences were found by location (Žman, Novigrad). According to the available literature, the influence of different irrigation practices on total phenolic acids has not been investigated. Our findings showed that in a drier year like 2021, SAN technology did not achieve better results compared to the other treatments. Compared to 2020, total phenolic acids were higher. This means that the influence of year probably had a greater significance than the actual practice that was applied.

In 2020, though no difference was found in the contribution of vanillic acid in the treatments, it was higher in Novigrad. In 2021, there was no difference among treatments C, T_2, and T_3 or between treatments T_1 and T_3. The difference in the content of vanillic acid in 2021 occurred spatially, and it was higher at the Žman location (Table 9). *p*-Coumaric acid was the highest in treatment C compared to the irrigated treatment, which did not significantly differ from each other in both research years. The contribution of *p*-coumaric acid was higher at the Žman location in 2020, while it was higher at the Novigrad location in 2021 (Table 9). These findings are corroborated with Faghim et al. (2021) [82] because the same climate (Mediterranean) was experienced in both our study and theirs. However, the soil in the research area of Faghim et al. [82] contained a larger amount of sand fraction in contrast to Croatian soil, which contains a large proportion of skeleton: almost half. Temperatures are 5 °C to 10 °C higher on average in the research area of Faghim et al. [82], because of the influence of an arid Saharan climate. These conditions of the soil and the average temperature during the year could bring differences in phenolic acid content because they show lower values in a drier year. Heat stress followed by drought cause unfavorable physiological reactions in the olive, which are ultimately seen in the change in the profile of phenolic compounds [63].

Total lignins were not determinate in 2020, and in 2021, and they did not significantly differ by treatment but were higher at the Žman location. Also, the influence of irrigation practices on the lignin content was not evident during 2008, 2009, and 2010 on the cultivar Frantoio [80]. Lignin is a highly ramified molecule and forms a solid component of the cell wall that forms a protective layer around the cellulose chains [85]. Therefore, the amount of water added during irrigation does not affect the lignin values in the olive fruit and consequently the olive oil.

Total secoiridoids in 2020 did not differ significantly, while in 2021, the highest value was shown by treatment C, followed by T_1 and T_3, and the lowest by treatment T_2. Secoiridoids were more prevalent at the Žman location in both years. Fregapane et al. [86] and Caruso et al. [80] corroborated this with their obtained results, confirming an increase in the content of total secoiridoids with a decrease in the amount of added water during irrigation treatments. The amount and distribution of secoiridoids present in olive tissue depends on various environmental factors, such as ripening cycle, geographical origin, and cultivation practices. In particular, the main secoiridoids components are immature stone (peel, pulp, and seed). Their quantity decreases as the fruit ripens [87]. Therefore, with a higher addition of water during irrigation, the fruit ripens faster and has a lower value of secoiridoids.

The content of total phenols in 2020 did not differ statistically with regard to irrigation regimes, while in 2021, the highest values was found in treatment C, then in T_1, and the lowest in treatments T_3 and T_2. Jukić Špika et al. [62] found that Oblica cv. grown on an extremely rocky and dry reclaimed karst soil partially agreed with obtained results. In 2015, the content of total phenols was the lowest at 75% ET; in 2016, there were no significant differences between treatments, while in 2017, the content of total phenols decreased linearly, and phenols were 65% lower in oils from fully irrigated trees (100% ET) than in the control treatment. Differences in the content of total phenols should be related to water stress. In peach trees, it has also been reported that soil moisture stress can be associated with an increase in phenol content in the fruit [88,89].

The obtained results show a higher effect of irrigation in extreme conditions. Due to the influence of climate change, irrigation will have a significant impact on the phenolic compounds in the final product, i.e., olive oil. In a drier year, the impact on total phenols is more significant. Therefore, when producing quality fruit and, consequently, oil, it is desirable to adapt the irrigation technology in individual microlocations to agroecological conditions and climate changes.

3.6. Influence of Irrigation and Location on the Composition of Fatty Acids in Olive Oil

The obtained profile of fatty acids in this research is in accordance with the expected values for EVOO according to EU regulation [47] and also in accordance with other works that followed the composition of fatty acids of VOO of the Coratina cultivar, in which the most abundant fatty acids were oleic, palmitic, and linoleic [89,90]. Irrigation and location partially influenced the composition of fatty acids, the sum (18:2t + 18:3t, SFA, MUFA, PUFA), and the ratio (oleic/linoleic) (Table 10). Thus, the effect of irrigation was determined in both years on four fatty acids (palmitic, palmitoleic, linoleic, and lignoceric), and on four in only one year of research 2021 (oleic, stearic, arachidic, and behenic).

In both years 2020 and 2021 for palmitic and lignoceric and only in 2021 for stearic, an increase in the share of irrigated variants (T_1, T_2, and T_3) was found compared to the control treatment (C). Conversely, irrigation reduced the proportion of arachidic and behenic fatty acids in 2021 and reduced the proportion of oleic fatty acids in 2020 in the T_3 treatment. In 2021, the proportion of linoleic acid in treatment T_1 was reduced compared to other treatments. At the same time, a different influence in the two years of research was determined on the proportion of palmitoleic and linolenic fatty acids (Table 10). Patumi et al. [64] found no differences in the composition of individual fatty acids in treatments of 0, 33, 66, and 100% of total evapotranspiration on the Kalamata cultivar, which partially agrees with the results obtained for six fatty acids (myristic, heptadecanoic, heptadecenoic, eicosenoic, behenic, and eicosenoic). Authors Freihat et al. [91] determined that there were changes between myristic and palmitic fatty acids with 0, 40, 60, and 80 L of weekly irrigation, which coincides with the results obtained in our research, while Faghim et al. [82] found this only for myristic fatty acid between treatments. As expected, oleic acid was the most abundant, and its value ranged from 76% to 77%, which, compared to Aparicio et al. [92] is a slightly lower value but slightly higher compared to Yu et al., [93] who found a value of 59.41% to 77.75% for the Coratina cultivar. As the proportion of oleic acid depends on the ago-ecological conditions of cultivation, this may be one of the reasons for the difference in the proportion between the two locations. The obtained trend related to the proportion of oleic fatty acid partially coincides with the published results of Jukić Šipka et al. [62], in which they irrigated with 0, 50, 75, and 100% of total evapotranspiration on the Oblica cultivar grown on meliorated karst. The results also partially overlap with other authors for this fatty acid; Freihat et al. [91] investigated the impact of additional irrigation on performance of Nabali and Grossa de Spain olives under semi-arid conditions in Jordan.

Table 10. Composition of fatty acids in olive oil Coratina cv. grown in different irrigation treatments (C, T_1, T_2, and T_3) at two locations (Žman, Novigrad) during the growing seasons of 2020 and 2021.

Factors Fatty Acids	**Year**	**Treatment (T)**				**Location (L)**		**T**	**L**	**T × L**
		C	$\mathbf{T_1}$	$\mathbf{T_2}$	$\mathbf{T_3}$	**Žman**	**Novigrad**	***p***	***p***	***p***
Myristic (C 14:0)	2020	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	n.s.	n.s.	*
	2021	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	0.01 ± 0.00	0.00 ± 0.00	0.01 ± 0.00	n.s.	n.s.	n.s.
Palmitic (C 16:0)	2020	11.68 ± 0.63 ^{c}	12.48 ± 0,10 ^{b}	12.67 ± 0.08 ^{b}	13.37 ± 0.14 ^{a}	12.24 ± 0.37 ^{b}	12.86 ± 0.08 ^{a}	***	***	***
	2021	11.81 ± 0.17 ^{c}	12.04 ± 0.14 ^{b}	12.23 ± 0.03 ^{ab}	12.35 ± 0.02 ^{a}	12.39 ± 0.08 ^{a}	11.83 ± 0.08 ^{b}	***	***	***
Palmitoleic (C 16:1)	2020	0.71 ± 0.06 ^{a}	0.60 ± 0.02 ^{b}	0.57 ± 0.01 ^{b}	0.57 ± 0.01 ^{b}	0.67 ± 0.03 ^{a}	0.56 ± 0.01 ^{b}	***	***	***
	2021	0.54 ± 0.02 ^{b}	0.53 ± 0.02 ^{c}	0.59 ± 0.02 ^{a}	0.58 ± 0.01 ^{a}	0.58 ± 0.01 ^{a}	0.55 ± 0.02 ^{b}	***	***	***
Heptadecanoic (C 17:0)	2020	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00	0.05 ± 0.00 ^{b}	0.05 ± 0.00 ^{a}	n.s.	**	**
	2021	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	0.04 ± 0.00	n.s.	n.s.	n.s.
Heptadecenoic (C 17:1)	2020	0.08 ± 0.00	0.08 ± 0.01	0.08 ± 0.00	0.08 ± 0.00	0.07 ± 0.00 ^{b}	0.08 ± 0.00 ^{a}	n.s.	***	**
	2021	0.07 ± 0.01	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.01	0.07 ± 0.00 ^{a}	0.06 ± 0.00 ^{b}	n.s.	**	n.s.
Stearic (C 18:0)	2020	2.35 ± 0.02	2.31 ± 0.06	2.31 ± 0.09	2.28 ± 0.07	2.43 ± 0.02 ^{b}	2.20 ± 0.03 ^{a}	n.s.	***	n.s.
	2021	2.43 ± 0.28 ^{a}	2.49 ± 0.25 ^{a}	2.20 ± 0.05 ^{b}	2.20 ± 0.14 ^{b}	1.93 ± 0.04 ^{b}	2.73 ± 0.10 ^{a}	***	***	***
Oleic (C 18:1)	2020	76.68 ± 0.37 ^{a}	76.31 ± 0.20 ^{a}	76.29 ± 0.09 ^{a}	75.66 ± 0.07 ^{b}	76.48 ± 0.21 ^{a}	76.00 ± 0.09 ^{b}	***	***	***
	2021	76.63 ± 0.12	77.02 ± 0.26	76.70 ± 0.22	76.57 ± 0.18	77.00 ± 0.16 ^{a}	76.46 ± 0.07 ^{b}	n.s.	***	***
Linoleic (C 18:2)	2020	6.48 ± 0.17	6.36 ± 0.14	6.31 ± 0.11	6.31 ± 0.09	6.32 ± 0.09 ^{b}	6.48 ± 0.17 ^{a}	n.s.	***	**
	2021	6.57 ± 0.07 ^{a}	6.04 ± 0.17 ^{b}	6.52 ± 0.24 ^{a}	6.48 ± 0.15 ^{a}	6.14 ± 0.12 ^{b}	6.67 ± 0.09 ^{a}	**	***	***
Linolenic (C 18:3)	2020	0.91 ± 0.02 ^{a}	0.78 ± 0.04 ^{b}	0.71 ± 0.01 ^{c}	0.70 ± 0.03 ^{c}	0.75 ± 0.04 ^{b}	0.80 ± 0.02 ^{a}	***	**	**
	2021	0.83 ± 0.05 ^{ab}	0.73 ± 0.02 ^{b}	0.67 ± 0.03 ^{a}	0.71 ± 0.05 ^{a}	0.82 ± 0.02 ^{a}	0.65 ± 0.02 ^{b}	***	***	***
Arachidic (C 20:0)	2020	0.43 ± 0.01	0.42 ± 0.00	0.41 ± 0.01	0.41 ± 0.01	0.42 ± 0.01	0.42 ± 0.00	n.s.	n.s.	n.s.
	2021	0.42 ± 0.03 ^{a}	0.43 ± 0.02 ^{a}	0.39 ± 0.00 ^{b}	0.39 ± 0.01 ^{b}	0.37 ± 0.00 ^{b}	0.44 ± 0.01 ^{a}	***	***	***
Eicosenoic (C 20:1)	2020	0.43 ± 0.01	0.43 ± 0.02	0.42 ± 0.01	0.40 ± 0.02	0.40 ± 0.01 ^{b}	0.44 ± 0.01 ^{a}	n.s.	***	***
	2021	0.44 ± 0.02	0.43 ± 0.02	0.42 ± 0.02	0.44 ± 0.02	0.47 ± 0.01 ^{a}	0.39 ± 0.01 ^{b}	n.s.	***	n.s.
Behenic (C 22:0)	2020	0.12 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00 ^{b}	0.12 ± 0.00 ^{a}	n.s.	*	*
	2021	0.11 ± 0.00 ^{a}	0.11 ± 0.01 ^{a}	0.10 ± 0.00 ^{b}	0.10 ± 0.00 ^{b}	0.10 ± 0.00 ^{b}	0.11 ± 0.00 ^{a}	***	***	***
Eicosenoic acid (C 22:1)	2020	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	n.s.	n.s.	n.s.
	2021	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00 ^{a}	0.00 ± 0.00 ^{b}	n.s.	**	n.s.
Lignoceric (C 24:0)	2020	0.06 ± 0.00 ^{a}	0.05 ± 0.00 ^{b}	0.05 ± 0.00 ^{ab}	0.05 ± 0.00 ^{b}	0.05 ± 0.00 ^{b}	0.06 ± 0.00 ^{a}	*	***	**
	2021	0.05 ± 0.00 ^{a}	0.05 ± 0.00 ^{ab}	0.05 ± 0.00 ^{b}	0.05 ± 0.00 ^{b}	0.05 ± 0.00	0.05 ± 0.00	**	n.s.	n.s.
∑ SFA	2020	14.70 ± 0.61 ^{c}	15.43 ± 0.07 ^{b}	15.61 ± 0.14 ^{b}	16.28 ± 0.16 ^{a}	15.3 ± 0.37 ^{b}	15.71 ± 0.09 ^{a}	***	***	***
	2021	14.88 ± 0.17 ^{b}	15.16 ± 0.16 ^{a}	15.01 ± 0.03 ^{ab}	15.13 ± 0.06 ^{a}	14.89 ± 0.08 ^{b}	15.20 ± 0.06 ^{a}	**	***	***
∑ MUFA	2020	77.91 ± 0.44 ^{a}	77.43 ± 0.20 ^{b}	77.37 ± 0.10 ^{b}	76.72 ± 0.08 ^{c}	77.63 ± 0.26 ^{a}	77.08 ± 0.09 ^{b}	***	***	***
	2021	77.68 ± 0.17	78.04 ± 0.30	77.78 ± 0.22	77.66 ± 0.16	78.12 ± 0.15 ^{a}	77.46 ± 0.07 ^{b}	n.s.	***	***
∑ PUFA	2020	7.40 ± 0.19 ^{a}	7.14 ± 0.15 ^{ab}	7.02 ± 0.12 ^{b}	7.01 ± 0.11 ^{b}	7.07 ± 0.13 ^{b}	7.21 ± 0.08 ^{a}	**	n.s.	***
	2021	7.40 ± 0.04 ^{a}	6.77 ± 0.15 ^{b}	7.19 ± 0.20 ^{a}	7.19 ± 0.14 ^{a}	6.96 ± 0.13 ^{b}	7.32 ± 0.08 ^{a}	**	***	*
Oleic/linoleic ratio (C18:1/C18:2)	2020	11.87 ± 0.27	12.02 ± 0.27	12.11 ± 0.21	12.01 ± 0.16	12.12 ± 0.14	11.89 ± 0.17	n.s.	n.s.	**
	2021	11.67 ± 0.14 ^{b}	12.80 ± 0.44 ^{a}	11.84 ± 0.46 ^{b}	11.85 ± 0.29 ^{b}	12.59 ± 0.27 ^{a}	11.49 ± 0.16 ^{b}	**	***	*

Results are presented as means ± standard errors (n = 3). Lowercase letters represent statistically significant differences between mean values for each main factor $p \leq 0.05$ obtained by two-way analysis of variance and the reverse Tukey test. First-order interactions (T × L.) are shown, with significance: n.s., not significant; ***, $p \leq 0.001$; **, $p \leq 0.01$; *, $p \leq 0.05$. Treatments: C, rainfed conditions; T_1, deficit irrigation (the usual producer's practice); T_2, deficit irrigation acquired by SAN technology in respect to phenological stages; T_3, irrigation with 100% of evapotranspiration (ETc) level. SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; n.d., not determined.

Location in both research years (2020 and 2021) influenced the proportion of palmitic, palmitoleic, heptadecenoic, stearic, oleic, linoleic, linolenic, behenic, and eicosenoic acids.

However, in 2020, the impact was determined for heptadecanoic and lignoceric and in 2021 for eicosenoic and arachidic (Table 10). In both years of research, higher values were found in Žman for palmitoleic, oleic, and eicosenoic acids, while the opposite was found for linolenic and behenic. Other fatty acids, namely palmitic, linoleic, heptadecenoic, and stearic, showed a different pattern of accumulation in the two years depending on the location. Pedoclimatic conditions and the year of cultivation significantly affect the composition of fatty acids [94], which is confirmed by the results obtained where the location proved to be a significant factor for the composition of almost all individual fatty acids (Table 10). Other authors such as El Qarnif et al., in 2019 [95], determined that oleic acid is influenced by location. It was also observed that warmer areas affect the expression of genes associated with the content of oleic and linoleic acids in cv. Arbequina more so than in Coratina. Such results partially overlap with the results obtained where only a large part of oleic acid but not linoleic acid was determined for Žman. This can be explained by the greater plasticity (adaptability) of the Coratina cultivar compared to some other olive cultivars, for example, Arbequina [96]. Given that the main problem in traditional olive cultivation in the Mediterranean is the occurrence of extreme weather conditions, such as drought with irrigation, the choice of cultivar can be of great importance for regular and sustainable production. Some of these cultivars can easily adapt to newly created conditions and their physiological and biochemical parameters, while others show unbalanced values, for example, of oleic acid content [93].

Irrigation increased the proportion of SFA in both years, with no difference between the treatments that were irrigated in 2021. Conversely, the proportion of MUFA was the highest in the C (77.91%) treatment and the lowest in the T_3 treatment (76.72%), while in the following year, there was no difference between the irrigated variants. A similar trend was shown by the share of PUFA, which showed a decreasing trend with larger amounts of added water. Irrigation had a slight effect on the oleic/linoleic ratio only in 2021, where the T_1 treatment had a different trend. Rallo et al. [6] in their review discussed several controversial papers that dealt with the influence of irrigation on the composition of fatty acids.

A similar trend for MUFA and PUFA and the opposite for SFA and oleic/linoleic ratio was obtained by Jukić Špika [62] in 2022 on the cultivar Oblica, which was irrigated at 0, 50, 75, and 100 % from evapotranspiration. In addition, they found that irrigation did not have the same effect on age, which was partly confirmed by obtained results and which we can connect with the strong influence of age on the composition of fatty acids [97]. Likewise, Borges et al. [98] determined that the composition of fatty acids of the Arbequina cultivar is greatly influenced by the growing conditions, which we can partially relate to the obtained results. Differences in the composition of fatty acids can also be linked to the strong influence of the cultivar, which was also established by Jukić Špika et al. [99]. The composition of fatty acids can vary depending on the time of occurrence of high temperature, which was found in sunflower by Rondanini et al. [100].

3.7. Influence of Irrigation and Location on Sensory Characteristics of Olive Oil

The positive sensory characteristics of olive oil, such as olive fruitiness, bitterness, and pungency, that we found were in accordance with the expected values for EVOO according to EU regulations [51]. Furthermore, not a single negative sensory property was found that would place the samples in a lower category according to the prescribed norms [51]. According to the intensity of fruitiness, bitterness, and pungency, we can classify the samples as medium-intensive in 2020 because the intensity of these properties was below 6 and as robust in 2021 because the intensity of the mentioned properties was higher than 6. Climatic factors, such as the amount of precipitation, can affect the mentioned intensities, so the reason for this difference may lie in a different distribution of precipitation between the two investigated years (Figures 1 and 2).

Increased amounts of water through irrigation reduced the odor of olive fruitiness under all treatments in 2020 compared to the control treatment. However, in 2021, there was no significant drop in fruitiness except for under the T_1 treatment. Such a trend in oil without irrigation or with minimal irrigation was determined in oil of the Cornicabra cultivar [101]. For the other properties, except for the apple odor, a stronger intensity was determined in 2021 compared to 2020 (Table 11). Similarly, a different influence of irrigation depending on the year was determined for the cultivar Cornicabra [86]. The odor of green grass/green leaves and chicory showed a slight trend of decrease with the increase in the amount of irrigation water, while the opposite was found for the odor of apple and tomato.

Similar to the olfactory attributes of the oil, the taste attributes were more pronounced in the 2021 compared to the 2020 research. Along with the odor of olive fruit, pungency and bitterness are the most important sensory attributes that distinguish high-quality olive oil [51]. In general, their intensity scores decreased with an increase in the amount of water used for irrigation. Thus, the treatment with the most added water (T_3) for both properties in both years was of lower intensity than the control, while treatments T_1 and T_2 were not significantly different from C. The sweet sensory descriptor increased in T_3, which is consistent with the reduction of bitterness and pungency properties in these samples. The overall score in treatment T_3 was lower compared to C, which was not irrigated, and the other treatments (T_1 and T_2) did not differ statistically significantly from C.

Table 11. Sensory attributes of smell and taste from Coratina cv. olive grown in different irrigation treatments (C, T_1, T_2, and T_3) at two locations (Žman, Novigrad) during the growing seasons of 2020 and 2021.

Factors Sensory Attributes	Year	Treatments (T)				Locations (L)		T	L	T × L
		C	T_1	T_2	T_3	Žman	Novigrad	*p*	*p*	*p*
Odor Sensory Characteristics										
Olive fruitiness	2020	5.78 ± 0.35 ^{a}	5.35 ± 0.22 ^{b}	5.32 ± 0.26 ^{b}	4.77 ± 0.09 ^{c}	5.79 ± 0.18 ^{a}	4.82 ± 0.06 ^{b}	***	***	***
	2021	6.73 ± 0.07 ^{a}	6.22 ± 0.18 ^{b}	6.33 ± 0.07 ^{ab}	6.42 ± 0.12 ^{ab}	6.38 ± 0.10	6.47 ± 0.10	*	n.s.	n.s.
Green grass/green leaves	2020	4.25 ± 0.46 ^{a}	3.54 ± 0.29 ^{b}	3.77 ± 0.42 ^{ab}	2.97 ± 0.2 ^{c}	4.35 ± 0.22 ^{a}	2.91 ± 0.11 ^{b}	***	***	*
	2021	5.42 ± 0.05 ^{a}	4.55 ± 0.38 ^{ab}	4.82 ± 0.22 ^{ab}	4.3 ± 0.27 ^{b}	4.58 ± 0.20	4.97 ± 0.22	*	n.s.	n.s.
Apple	2020	2.37 ± 0.28	2.53 ± 0.32	1.88 ± 0.22	2.50 ± 0.13	2.07 ± 0.18 ^{b}	2.58 ± 0.16 ^{a}	n.s.	*	n.s.
	2021	0.75 ± 0.34 ^{b}	0.83 ± 0.31 ^{b}	1.18 ± 0.53 ^{b}	2.13 ± 0.37 ^{a}	2.03 ± 0.21 ^{a}	0.42 ± 0.18 ^{b}	***	***	*
Tomato	2020	0.00 ± 0.00 ^{c}	1.02 ± 0.22 ^{ab}	0.60 ± 0.21 ^{b}	1.20 ± 0.10 ^{a}	0.52 ± 0.16 ^{b}	0.89 ± 0.18 ^{a}	***	*	n.s.
	2021	0.00 ± 0.00 ^{b}	0.00 ± 0.00 ^{b}	0.00 ± 0.00 ^{b}	0.62 ± 0.28 ^{a}	0.31 ± 0.16 ^{a}	0.00 ± 0.00 ^{b}	***	***	***
Almond	2020	2.55 ± 0.35	2.17 ± 0.25	2.2 ± 0.22	1.85 ± 0.07	2.41 ± 0.19 ^{a}	1.98 ± 0.15 ^{b}	n.s.	*	*
	2021	1.90 ± 0.08	2.17 ± 0.11	2.37 ± 0.23	2.08 ± 0.14	2.17 ± 0.14	2.09 ± 0.08	n.s.	n.s.	n.s.
Aromatic herbs	2020	2.2 ± 0.16 ^{a}	1.72 ± 0.17 ^{ab}	1.53 ± 0.14 ^{b}	1.67 ± 0.22 ^{ab}	1.98 ± 0.15 ^{a}	1.58 ± 0.11 ^{b}	*	*	n.s.
	2021	2.92 ± 0.08	2.85 ± 0.15	2.83 ± 0.11	2.42 ± 0.24	2.64 ± 0.14	2.87 ± 0.09	n.s.	n.s.	n.s.
Chicory/rocket	2020	2.6 ± 0.46	2.27 ± 0.35	2.27 ± 0.34	2.02 ± 0.12	2.93 ± 0.17 ^{a}	1.65 ± 0.11 ^{b}	n.s.	***	*
	2021	3.7 ± 0.15 ^{a}	3.55 ± 0.14 ^{a}	3.67 ± 0.12 ^{a}	2.8 ± 0.24 ^{b}	3.41 ± 0.20	3.45 ± 0.10	***	n.s.	*
OTHER (green banana peel/green almond)	2020	2.27 ± 0.88 ^{b}	1.40 ± 0.65 ^{ab}	1.58 ± 0.52 ^{ab}	1.13 ± 0.51 ^{b}	2.94 ± 0.25 ^{a}	0.25 ± 0.18 ^{b}	*	***	*
	2021	3.10 ± 0.19 ^{ab}	3.33 ± 0.30 ^{a}	2.90 ± 0.37 ^{ab}	2.18 ± 0.39 ^{b}	2.78 ± 0.31	2.98 ± 0.17	*	n.s.	*
Taste Sensory Characteristics										
Bitter	2020	5.78 ± 0.39 ^{a}	5.52 ± 0.30 ^{ab}	5.6 ± 0.33 ^{ab}	5.27 ± 0.44 ^{b}	6.34 ± 0.07 ^{a}	4.74 ± 0.10 ^{b}	**	***	n.s.
	2021	6.72 ± 0.22 ^{a}	6.47 ± 0.14 ^{a}	6.38 ± 0.20 ^{a}	6.02 ± 0.10 ^{b}	6.69 ± 0.14 ^{a}	6.10 ± 0.06 ^{b}	***	***	*
Pungent	2020	6.58 ± 0.38 ^{a}	6.25 ± 0.36 ^{ab}	6.23 ± 0.40 ^{ab}	5.90 ± 0.56 ^{b}	7.17 ± 0.07 ^{a}	5.32 ± 0.14 ^{b}	**	***	**
	2021	7.13 ± 0.08 ^{a}	7.00 ± 0.13 ^{a}	6.78 ± 0.05 ^{ab}	6.57 ± 0.14 ^{b}	6.84 ± 0.13	6.90 ± 0.03	**	n.s.	n.s.
Sweet	2020	0.92 ± 0.42 ^{b}	0.92 ± 0.45 ^{b}	0.95 ± 0.43 ^{ab}	1.62 ± 0.46 ^{a}	0.17 ± 0.11 ^{b}	2.03 ± 0.15 ^{a}	*	***	n.s.
	2021	0.92 ± 0.42 ^{b}	0.92 ± 0.45 ^{b}	0.95 ± 0.43 ^{ab}	1.62 ± 0.46 ^{a}	0.17 ± 0.11 ^{b}	2.03 ± 0.15 ^{a}	*	***	n.s.
Astringent	2020	2.08 ± 0.43	2.22 ± 0.40	2.03 ± 0.43	1.83 ± 0.42	2.93 ± 0.06 ^{a}	1.16 ± 0.14 ^{b}	n.s.	***	n.s.
	2021	4.20 ± 0.14 ^{a}	3.93 ± 0.24 ^{ab}	4.23 ± 0.18 ^{a}	3.67 ± 0.20 ^{b}	4.40 ± 0.09 ^{a}	3.62 ± 0.09 ^{b}	***	***	n.s.

Table 11. *Cont.*

Factors Sensory Attributes	Year	Treatments (T)				Locations (L)		T	L	T × L
		C	T_1	T_2	T_3	Žman	Novigrad	*p*	*p*	*p*
		Overall Sensory Descriptors								
Complexity	2020	8.92 ± 0.35	8.42 ± 0.20	8.67 ± 0.25	8.50 ± 0.00	9.00 ± 0.14 [a]	8.25 ± 0.12 [b]	n.s.	***	**
	2021	9.42 ± 0.08	9.00 ± 0.22	9.08 ± 0.08	8.92 ± 0.15	9.08 ± 0.10	9.13 ± 0.13	n.s.	n.s.	n.s.
Harmony	2020	9.17 ± 0.11	9.08 ± 0.24	9.17 ± 0.11	8.92 ± 0.2	9.00 ± 0.11	9.17 ± 0.13	n.s.	n.s.	*
	2021	9.25 ± 0.11	9.00 ± 0.13	9.17 ± 0.11	9.00 ± 0.13	8.96 ± 0.04 [a]	9.25 ± 0.10 [b]	n.s.	*	n.s.
Persistency	2020	8.92 ± 0.24 [a]	8.67 ± 0.21 [ab]	8.75 ± 0.25 [ab]	8.25 ± 0.34 [b]	9.13 ± 0.07 [a]	8.17 ± 0.17 [b]	*	***	n.s.
	2021	9.92 ± 0.08	9.58 ± 0.2	9.58 ± 0.15	9.25 ± 0.28	9.58 ± 0.17	9.58 ± 0.12	n.s.	n.s.	n.s.
Overall sensory score	2020	8.42 ± 0.15 [a]	8.17 ± 0.12 [b]	8.29 ± 0.08 [ab]	8.13 ± 0.11 [b]	8.48 ± 0.06 [a]	8.02 ± 0.05 [b]	**	***	n.s.
	2021	8.67 ± 0.05 [a]	8.54 ± 0.08 [ab]	8.54 ± 0.08 [ab]	8.33 ± 0.08 [b]	8.46 ± 0.07 [b]	8.58 ± 0.05 [a]	**	*	*

Results are presented as means ± standard errors (n = 3). Lowercase letters represent statistically significant differences between mean values for each main factor $p \leq 0.05$ obtained by two-way analysis of variance and the reverse Tukey test. First-order interactions (T × L.) are shown, with significance: n.s., not significant; ***, $p \leq 0.001$; **, $p \leq 0.01$; *, $p \leq 0.05$. Treatments: C, rainfed conditions; T1, deficit irrigation (the usual producer's practice); T2, deficit irrigation acquired by SAN technology in respect to phenological stages; T3, irrigation with 100% of evapotranspiration (ETc) level.

When location was considered, Žman had odor and taste properties of greater intensity compared with Novigrad, except for the tomato odor in 2020 and the overall rating in 2021. Similar to the results of Rosati et al. [22], agronomic practices can affect the increase in bitterness and pungency and the reduced sweetness of the oil, which in this case could also be one of the reasons for the differences we found between the two locations we investigated. However, some authors such as Jukić Špika et al. [99] pointed out that the cultivar has a greater influence on the composition of the oil than the location and time of harvest, which was partially confirmed by obtained results and small differences found between locations. It is well known that the VOO of the Coratina cultivar contains a high proportion of carotenoids, chlorophyll, tocopherols, and phenolic compounds and a high level of volatile substances, demonstrating its excellent nutritional qualities and pleasant flavors [93], which is also confirmed by our work. Since global warming affects the composition of VOO, for example, due to phenols and fatty acids contents [22], it is to be expected that this change can also come from a change in the sensory profile of oil. Nissim et al. [22] determined that the cultivar has a different response to changes in temperature, so the oil of the Souri cultivar was much less affected by high temperature than the Barnea, Koroneiki, Coratina, and Picholine cultivars.

4. Conclusions

The field experiment conducted at two locations across two consecutive years aimed to determine the impact of four different irrigation managements on the Coratina olive cultivar in karst soil in Croatia with regard to olive fruit fly infestation, healthy fruit morphology, oil yield and quality, and the composition of the obtained oil. The irrigated treatments were compared with the non-irrigated control treatment, which actually represents the majority of cultivated olives in Croatia.

The intensity of the olive fly attack on the irrigation treatments was higher in the year of stronger attack (2021) compared to the control treatment, which was not confirmed in the previous year. The pulp mass, independently of the year, increased in irrigated treatment (ranging from 1.04 to 1.65 in C to 2.25 and 2.30 in the irrigated treatments) by almost 4 to 9 percent and resulted in a higher oil content on fresh weight basis (ranging from 16.39% to 17.85% in C to 19.48% to 23.26% in the irrigated treatments). However, fruit yield per tree was only location-dependent. The basic quality parameters used for oil classification were in the limits for EVOO category and only slightly influenced by irrigation. The sensory properties were more influenced by irrigation, although it should be emphasized that all samples met the limits for the largest category of olive oil according to the sensory parameters as well. Individual phenols were influenced by irrigation, but the total phenols among years might not be influenced by irrigation. The decrease in total phenols was determined under the influence of irrigation. The composition of fatty acids was more influenced by location than by irrigation itself. Unsaturated fatty acids, namely PUFA and MUFA, were the highest at the Novigrad location compared to the Žman location. The intensity of the taste and odor of the oil from the irrigated cultivars was slightly reduced compared to the control treatment. Based on the large number of monitored parameters, it is hard to single out any irrigated treatment as the most efficient one in all parameters, but we assume that T_2 (SAN technology) compared to T_3 saved more water and compared to T_1 might save farmers time and labor.

However, due to the limited amounts of irrigation water and the negative environmental consequences associated with irrigation, it is necessary to design models according to growing conditions that will help the producer to add optimal amounts of water. In general, the obtained results justify the use of the irrigation deficit SAN technology when making irrigation decisions with regard to the appearance of fly infestation, oil yield, and the composition and quality of the oil obtained. Along with these results, the use of irrigation deficit reduces the water use rate, and the producer's time is saved. Evident climate changes, according to estimates, will hit the Mediterranean area to the greatest extent; therefore, in the future, new technologies that include precision agriculture will be necessary to mitigate the negative impact on the yield and profitability of olive production.

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