J Food Sci Technol
https://doi.org/10.1007/s13197-022-05362-y

REVIEW ARTICLE

A global systematic review and meta-analysis on prevalence of the aflatoxin B_1 contamination in olive oil

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Revised: 16 December 2021 / Accepted: 21 December 2021

Abstract Olive oil can be contaminated by fungal toxins; therefore, it is necessary to monitor the incidence of mycotoxins in this oil. In the present study, the pooled prevalence of detectable aflatoxin B_1 (AFB_1) in olive oil was evaluated using systematic review and meta-analysis approach from 1 January 1991 to 31 December 2020 (30 years study). The search was conducted via electronic databases involving Scopus, Web of Science, PubMed, Agris and Agricola. Synonyms were collected from combination of the MESH, Agrovoc and free text method. After screening and selection process of primary researches, full texts of eligible researches (46 studies) were evaluated and data of the nine studies as included researches were extracted. Random effect model was used to estimate the pooled prevalence of AFB_1 in olive oil and weighing model of Dersimonian–Laired was applied. Summary measure of mycotoxin prevalence was estimated using Metaprop module of STATA and 95% confidence interval (CI) were calculated using the Binomial Exact Method. Pooled prevalence of AFB_1 in olive oils were 32% (95% CI 8–56%) which means that 68% of olive oil were free of detectable contaminants of AFB_1. Due to controversy over the results of primary studies, future researches and consequent subgroup analysis based on the main variables affecting the aflatoxins contamination in olive oil are recommended to achieve the conclusive results.

Keywords Aflatoxin · Meta-analysis · Mycotoxins · Occurrence · Olive oil

Abbreviations

AFB_1, afla B1, aflB1, AFB1	Aflatoxin B_1
AFG_1	Aflatoxin G_1
AFs, aflas, afls, AFS, AF	Aflatoxins
CI	Confidence interval
D+L	Dersimonian–Laired
EC	European Commission
EVOO	Extra virgin olive oil
FAO	Food and Agriculture Organization
IARC	International Agency for Research on Cancer
IOC	International Olive Council
LOD	Limit of detection
LOQ	Limit of quantification
MRLs	Maximum residual limits
OTA	Ochratoxin A
REM	Random effect model
TAF, AFT	Total aflatoxin
VOO	Virgin olive oil
WHO	World Health Organization

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Published online: 12 January 2022

Introduction

Mycotoxins are biological toxins produced by specific fungi and can be presented in agricultural products under warm and humid conditions as a result of mold contamination of crops, during both pre- and post-harvest. They may cause health hazards to humans and livestock, ranging from acute poisoning to long-term effects such as immune deficiency and cancer (Cavaliere et al. 2007; Ferracane et al. 2007). Almost 25% of the world's harvested crops are spoiled by mycotoxins, this causes annual significant losses in agricultural and industrial sectors in billions of dollars (Agriopoulou et al. 2020). According to the International Agency for Research on Cancer (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans 2012), mycotoxins are hazardous contaminants to human and animal health and as top ten hazards based on Rapid Alert System for Food and Feed. Among the several hundred mycotoxins identified until now, around a dozen have gained the most attention due to their severe effects on human health and their presence in food (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans 2012; Agriopoulou et al. 2020). Based on the report of the IARC and WHO in 2016, 500 million people are exposed to natural toxins, such as mycotoxins, daily and 160 million children under the age of five are stunted in developing countries (Agriopoulou et al. 2020). Public concern about possible presence of mycotoxins in food has increased in recent years due to the increasing awareness of the health impact.

Aflatoxins (AFs) are a group of greatly toxic mycotoxins produced by certain fungi of the genus *Aspergillus,* such as *Aspergillus flavus* and *Aspergillus parasiticus* (Markaki 2010). AFs are potent carcinogenic, teratogens, hepatocarcinogenic, nephrotoxic and mutagens mycotoxins (Ferracane et al. 2007; Markaki 2010). Proportion of AFs in mycotoxins were reported 82% in 2018 (Agriopoulou et al. 2020). Four main AFs (B_1, B_2, G_1, and G_2) of 20 occur naturally in contaminated plant products (Cavaliere et al. 2007). Aflatoxin B_1 (AFB_1) has classified in Group 1 as human carcinogen (IARC Working Group on the Evaluation of Carcinogenic Risks to Humans 2012; FAO/WHO 2015) which usually is the most concerning and poisonous among these toxins. Consequently, detection of AFB_1 has become important in terms of safety, import and export of food products.

Vegetable oils are important part of the human diet; therefore, safety of these oils and their conformity assessment based on national and international standards are essential and necessary to maintain the consumer's health and fair trade. Soybean, rapeseed, sunflower seed, peanut, sesame and olive oils are major oils which extensively used for cooking in the world (Bao et al. 2010; Zhao et al. 2017a). Vegetable oil is known as one of the main mycotoxin-contaminated foodstuffs (Bordin et al. 2014; Li et al. 2019). AFB_1 is reported as one of the main harmful constituents and risk factors of edible oils (Liu et al. 2017). Existing reports reveal the contamination of majority of edible oil-yielding seeds by various fungi, resulting mycotoxins production (Bhat and Reddy 2017). Since most of the mycotoxins are fat soluble and not easily eliminated from the body, mostly accumulated in fatty tissues (Idris et al. 2010).

Different kinds of olive oils are popular worldwide, especially in Mediterranean countries they have notable increase in consumption rate (Özcan et al. 2019; Gumus et al. 2020; Xia et al. 2021; Shavakhi et al. 2021). Virgin olive oil was defined as a functional food and source of phytochemicals and also recently considered as protecting against respiratory viral infections and COVID-19 (Alkhatib 2020). Contamination of aflatoxin may occur during growth, harvesting, storage, processing, and transportation of crops (Agriopoulou et al. 2020; Xia et al. 2021). Virgin olive oils can be contaminated by mycotoxins and because of chemical and thermal stability of these toxins, the contaminations remain during food processing such as cooking and frying (Afzali et al. 2012; Agriopoulou et al. 2020). Literature review supports the presence of mycotoxins in olive and olive oil (Daradimos et al. 2000; Papachristou and Markaki 2004; Finoli et al. 2005; Roussos et al. 2006; Ghitakou et al. 2006; Cavaliere et al. 2007; Ferracane et al. 2007; Ben Rejeb et al. 2009; Bao et al. 2010; Markaki 2010; Alamprese 2014; Nabizadeh et al. 2018; Hidalgo-Ruiz et al. 2019). Presence of AFs in olive and consequently extracted oil may raise consumer concerns regarding safety of these products; therefore, monitoring of these contaminants is important.

There are several review articles in literature on measuring of mycotoxins (Rahmani et al. 2009; Bordin et al. 2014; Selvaraj et al. 2015; Ma et al. 2016; Bhat and Reddy 2017; Liu et al. 2017; Tantaoui-Elaraki et al. 2018; Mahato et al. 2019; Ouakhssase and Ait Addi 2020; Xia et al. 2021). There are also, systematic review and meta-analysis of mycotoxin in different food such as yeast based, cereal based products, coffee and coffee-based products and milk (Mousavi Khaneghah 2020; Fakhri et al. 2019; Campagnollo et al. 2020; Farhadi et al. 2021; Sarmast et al. 2021). Based on our knowledge, there is no specific review, systematic review or meta-analysis on mycotoxins in olive oils. Therefore, the aim of this study was monitoring the prevalence of AFB_1 in olive oil which were detected by world researchers between 1991 and 2020 using systematic review and meta-analysis approach.

Material and methods

Search strategy

Search strategy was performed to obtain all primary researches regarding the prevalence of AFB_1 in olive oil. 30 years study (1 January 1991–31 December 2020) was selected as period of the investigation. There was no language limitation in search strategy. The study was conducted using electronic databases including Scopus, Web of Science, PubMed, Agris and Agricola to assure sufficient and satisfactory coverage (Bramer et al. 2017). Scholar google and references list of included researches were reviewed to obtain more relevant studies (Fig. 1).

Synonyms were collected from combination of MESH, Agrovoc and free text method. Free text method is based on asking from experts. The following search keywords or terms were used: (mycotoxin) (aflatoxin) (toxin AND fungal) ("fungal toxin") ("toxigenic fungi") ("aflatoxigenic fungi") ("total aflatoxin") (aflas) (afls) (afla B1) (aflB1) (TAF) (AFT) (AFS) (AFB1) (AFs) (AF) (aflatoxin B1)) ("olive oil") (oil) (oil AND olive) ("edible oil") ("vegetable oil")). The first or fundamental electronic database was Scopus, and then search syntax was adopted for others. Search syntax for scopus was as follows: (TITLE-ABS(mycotoxin) OR TITLE-ABS(aflatoxin) OR TITLE-ABS(toxin AND fungal) OR TITLE-ABS("fungal toxin") OR TITLE-ABS("toxigenic fungi") OR TITLE-ABS("aflatoxigenic fungi") OR TITLE-ABS("total aflatoxin") OR TITLE-ABS(aflas) OR TITLE-ABS(afls) OR TITLE-ABS(afla B1) OR TITLE-ABS(aflB1) OR TITLE-ABS(TAF) OR TITLE-ABS(AFT) OR TITLE-ABS(AFS) OR TITLE-ABS(AFB1) OR TITLE-ABS(AFs) OR TITLE-ABS(AF) OR TITLE-ABS(aflatoxin B1)) AND (TITLE-ABS("olive oil") OR TITLE-ABS(oil) OR TITLE-ABS(oil AND olive) OR TITLE-ABS("edible oil") OR TITLE-ABS("vegetable oil")) AND (PUBYEAR < 2021 AND PUBYEAR > 1990). Search syntax for web of science was as follows: (TS = (mycotoxin) OR TS = (aflatoxin) OR TS = ((toxin AND fungal)) OR TS = ("fungal toxin") OR TS = ("toxigenic fungi") OR TS = ("aflatoxigenic fungi") OR TS = ("total aflatoxin") OR TS = (aflas) OR TS = (afls) OR TS = (afla B1) OR TS = (aflB1) OR TS = (TAF) OR TS = (AFT) OR TS = (AFS) OR TS = (AFB1) OR TS = (AFs) OR TS = (AF) OR TS = (aflatoxin B1)) AND (TS = ("olive oil") OR TS = (oil) OR TS = ((oil AND olive)) OR TS = ("edible oil") OR TS = ("vegetable oil")) AND PY = (1991–2020).Search syntax for pubmed was: (Mycotoxin[all] OR Aflatoxin[all] OR (toxin[all] AND fungal[all]) OR "fungal toxin"[all] OR "toxigenic fungi"[all] OR "aflatoxigenic fungi"[all] OR "total aflatoxin"[all] OR aflas[all] OR afls[all] OR afla B1[all] OR aflB1[all] OR TAF[all] OR AFT[tiab] OR AFS[tiab] OR AFB1[tiab] OR AFs[all] OR AF[all] OR aflatoxin B1[all]) AND ("olive oil"[all] OR oil[all] OR (oil [all] AND olive[all]) OR "edible oil"[all] OR "vegetable oil"[all]) AND 1991/01/01:2019/12/31[dp]. Search syntax for Agris and Agricola were as follows consequently: subject: (oil) + (mycotoxin) + publicationDate: [1991–2020] and Subject("olive oil") AND Subject(aflatoxin)(DATE = 1991–2020).

Screening of primary research

Screening process was performed to evaluate primary researches according to title and abstract. Based on the title and abstract, some primary researches which have not investigated on the prevalence of mycotoxin or AFs in olive oil were excluded. Before screening, primary researches were excluded due to duplication using Mendeley reference management software (Elsevier, Mendeley Ltd. London, UK).

Selection of primary research

After the title and abstract screening, selection process was carried out by F.SH. aan A.R. based on full text of the selected publications. The following criteria were used to include researches: (a) Prevalence of AFB_1 was reported, or it could be calculated based on available data in primary research, (b) Any category and subgroup of olive oils such as virgin olive oil, refined, labelled, not labelled, organic were acceptable, (c) Any detection methods of AFB_1 analysis were acceptable (d) There was no language limitation. Disagreements between two authors were resolved by consensus strategy. Selection of AFB_1 was based on the majority and public health importance of the studies investigated on olive oil. If the full texts of the research were not accessible, they were obtained through correspondence with the authors.

Data extraction

Data of the eligible researches were extracted by F.SH. and Z.P.V., and disagreements were resolved by consensus strategy. The collected data of each primary research were extracted and summarized as first author, research year, country, sample size of olive oil, sampling place, olive oil type, aflatoxins detected, number of positive aflatoxin(s), detection method, limit of detection (LOD) and the limit of quantification (LOQ) (Table 1).

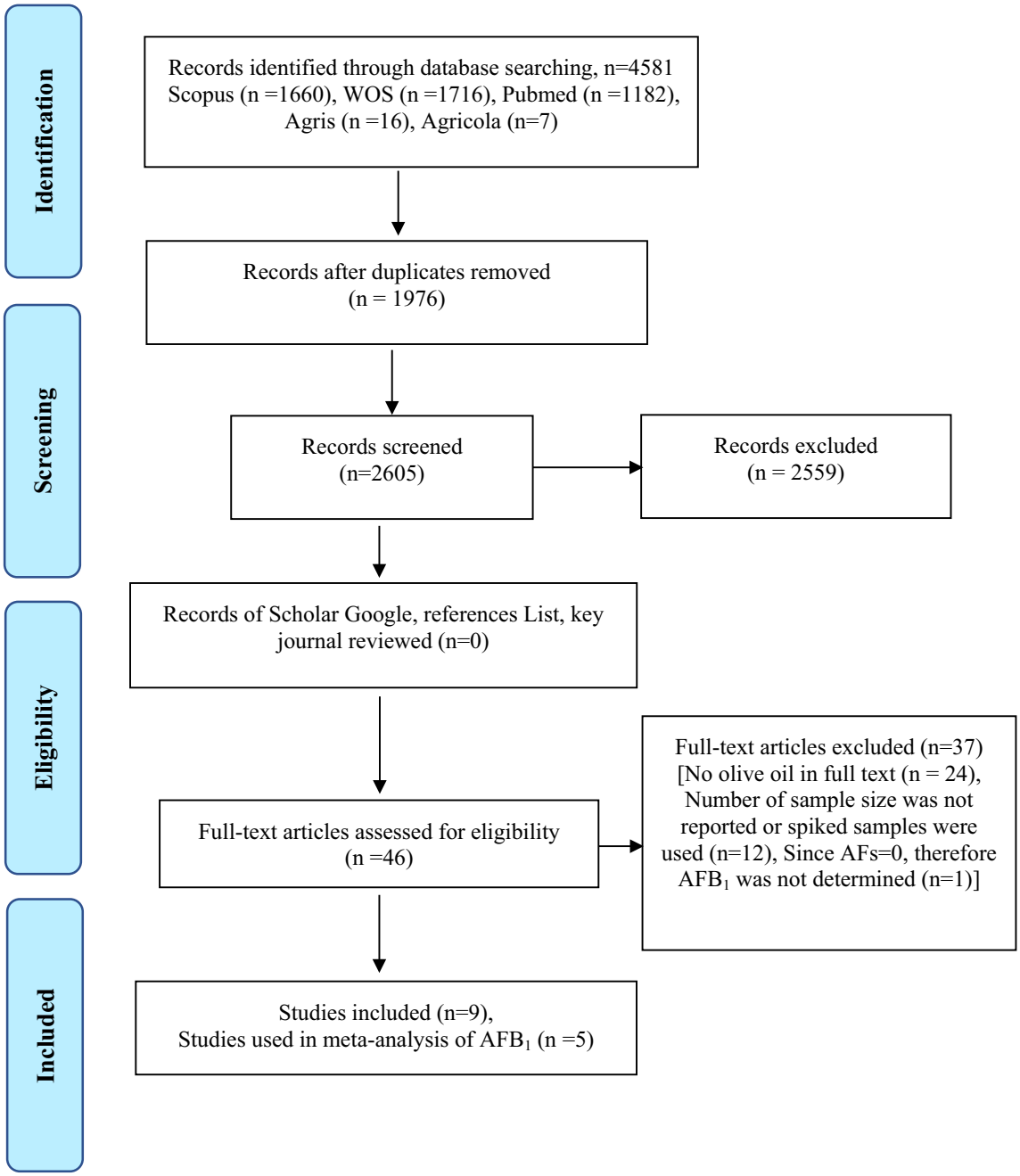

Fig. 1 PRISMA flow diagram of the selection process

Results and discussion

Statistical analysis/meta-analysis

Due to severe methodological heterogeneity, random effect model (REM) was used for combination to estimate the pooled prevalence of AFB_1 in olive oil with weighing model of Dersimonian–Laired or D + L (DerSimonian and Kacker 2007). If occurrence of AFB_1 was not available in the research, it was calculated based on the related raw data. According to the positive quantity of reported AFB_1 in olive oil samples and number of samples, the pooled prevalence of mycotoxins was estimated using Metaprop module of STATA (Nyaga et al. 2014). Meta-analysis method was performed using STATA (Release 14.1 statistical software. College Station, Texas, USA). *P*-value < 0.05 was considered statistically significant. Since the prevalence of less than 0.1 for even one study indicates that prevalence does not have a normal distribution, 95% confidence interval (CI) was calculated using the Binomial

Table 1 Main characteristics of the included studies

No	First author	Publish year	Country	Sample size of olive oil	Sample origin	Type of olive oil	Aflatoxins detected	Number of Positive Aflatoxin	Detection instrument	LOD (μg kg^{-1})	LOQ (μg kg^{-1})
1	Hidalgo-Ruiz	2019	Spain	153	Laboratorio Tello, from Jaen and local supermarket	EVOO1, OO2, lampante, refined olive pomace oil and crude olive pomace oil	B1, B2, G1, G2	B1 = 0 B2 = 0 G1 = 6 G2 = 24	UHPLC-MS–MS	B1, B2, G1, G2 (0.5 μg kg^{-1})	–
2	Yu	2019	Singapore	1	Local markets	Olive oil	B1	B1 = 0	LTC with IMSPE followed by FL detection	0.0048	0.0126
3	Nabizadeh	2018	Iran	30	Local supermarkets	15 refined and 15 unrefined olive oil	B1, B2, G1, G2	B1 = 0 B2 = 2	HPLC-FLD	B1(0.16), B2(0.04), G1(0.16), G2(0.04)	B1(0.5), B2(0.12), G1(0.5), G2(0.12)
4	Zhao	2017	China	10	Local markets	Olive oil	B1, B2, G1, G2	B1 = 0 B2 = 0 G1 = 0 G2 = 0	HPLC–MS/MS	B1(0.05), B2(0.04), G1(0.04), G2(0.05)	B1(0.18), B2(0.13), G1(0.14), G2(0.18)
5	Cavaliere	2007	Italy	35	Institute for experimental olive cultivation and Retail market	Institute for experimental olive cultivation (EVOO (7), VOO3 (8), Virgin Lampante (5) Retail Market (EVOO, 8; VOO, 8)	B1, B2, G1, G2	B1 = 3 B2 = 0 G1 = 0 G2 = 0	LC–MS/MS	B1(0.2), B2(0.2), G1(0.4), G2(0.3)	B1(0.4), B2(0.5), G1(0.9), G2 (0.9)
6	Ferracane	2007	Italy	30	Olive press plants and supermarkets (15 Moroco and 15 Italy	VOO	B1	B1 = 3	HPLC	0.25	–
7	Finoli	2005	Italy	28	Sicilian traditional and organic agriculture	EVOO	B1, B2, G1, G2	B1 = 7	HPLC	–	–
8	Papachristou and Markaki,	2004	Greece	50	25 from producer 25 from Athens market	VOO	B1	B1 = 12	HPLC with fluorescence detection	56×10^{-3}	
9	Daradimos	2000	Greece	50	Greek oil company	VOO	B1	B1 = 36	HPLC-FD	2.8×10^{-3}	–

1 = Extra virgin olive oil, 2 = Olive Oil, 3 = Virgin Olive Oil

Exact Method. Assuming that prevalence of AFB_1 does not have a normal distribution, prevalence index was computed using the logit of prevalence and the standard error of logit prevalence. Evaluation of heterogeneity based on subgroup analysis was not possible because it required at least four studies along with reported essential data in details.

Process of eligible researches

Figure 1, shows the flow diagram of this study. In the identification step, among the 4581 primary researches reviewed from 1991 to 2020 in all databases including Scopus (n = 1505; conference papers = 155), Web of Science (n = 1658, meeting abstracts and proceeding papers = 58), PubMed (n = 1182), Agris (n = 16) and Agricola (n = 7), 1976 researches were excluded due to duplication. Scholar google and references list also assessed for additional researches. In the screening step, titles and abstract of 2605 studies were evaluated and 2559 studies considered as irrelevant based on inclusion criteria stated before. Full-text of 46 articles assessed for eligibility and 37 research were excluded. Finally, based on the full texts, nine primary researches (K) with 387 (N) samples were included (Fig. 1). Eight of the included papers were in English and one was in Italian language. Since Italy, Spain and Greece are the main producing countries of olive oil in the world, included researches are also mainly from these countries. In Scopus database, the rank order for language were English, Chinese, Russian, Danish, Portuguese, German, French, Japanese, Persian, and Italian from the countries of China, United States, India, Brazil, Egypt, Iran, Germany, United Kingdom, Italy, and Japan. PRISMA Flow Diagram was used (Moher et al. 2009) to present this process.

Prevalence of AFB_1 and included researches were shown in horizontal and vertical axes of forest plot (Fig. 2) respectively. Prevalence, confidence interval and weight of each study can be seen for each study. No null zone in the forest plot is due to the descriptive study of prevalence. Individually, incidence rate of AFB_1 contamination were 9% (95% CI 2–23%), 72% (95% CI 58–84%), 10% (95% CI 2–27%), 46% (95% CI 28–66%), 24% (95% CI 13–38%) respectively (Daradimos et al. 2000; Papachristou and Markaki 2004; Finoli et al. 2005; Cavaliere et al. 2007; Ferracane et al. 2007). While the rhomboid in the Fig. 2 shows the overall estimate of prevalence for five primary researches (K) and 193 (N) samples. Summary measure of AFB_1 in olive oil was 32% with 95% confidence interval of (8–56%). I^2 which measures statistical heterogeneity was obtained 94.96% for AFB_1 in olive oil with P value of < 0.05 which shows the highly severe heterogeneity (Higgins and Thompson 2002). Studies with the prevalence value of zero for aflatoxin B_1 were excluded from meta-analysis (Zhao et al. 2017a; Nabizadeh et al. 2018; Hidalgo-Ruiz et al. 2019; Yu et al. 2019). Length of the line in the forest plot is inversely related to the sample size. In this regard, research with the longest line is due to the smallest sample size of 28 (Finoli et al. 2005).

Level of contaminants in various countries and regions are different because of diverse geographic location and climate (Xia et al. 2021). Analytical performance is also leading to diversity in contamination results (Duarte et al. 2009). Certain studies of decades ago with low limit of detection, reported that olive are insufficient substrates for AFs contamination (Eltem 1996). However, with the progress in analysis methods, numerous other studies have documented various levels of AFs in different vegetable oils. Some occurrences of aflatoxin (< 10 µg/kg) in olive oil have been identified from Greece, Spain, Morocco, and Northern Africa (Bao et al. 2010). Olive oil was also reported as a challenging matrix due to rising the matrix effects of lipids, fatty acids, and pigments in vegetable oil which hurt the instruments (Li et al. 2019). Therefore, highly efficient sample pretreatment techniques, and sensitive detection methods are considered as great challenges for the accurate detection of different mycotoxins in these oils.

AFB_1 and ochratoxin A (OTA) are the most typical co-occurred mycotoxins found in plants. Thus, synergistic effects between the two mycotoxins could occur (Rahmani et al. 2009). Olive oil is also recognized as susceptible to OTA contamination, due to improper storage leading to the mold growth (Duarte et al. 2009). OTA was detected in 33% of Sicilian EVOO samples obtained from traditional oils and 15% of organic ones (Finoli et al. 2005). Low level of OTA contamination (maximum value of 1.86 ng/g.) with prevalence of 20% in Greek olives samples also reported from different origins, varieties (black or green), and applications including table olive or oil producing (Ghitakou et al. 2006). Conversely, OTA was reported in 88% of olive oil from different origin of producers and marketplaces in Greece (Papachristou and Markaki 2004). When olives are deposited for a couple of days in environments which support the mold growth, mycotoxin contamination may occur (Ben Rejeb et al. 2009; Alamprese 2014; Tantaoui-Elaraki et al. 2018; Hidalgo-Ruiz et al. 2019). Issues related to quality control, inappropriate production technologies, hot climate and improper storage conditions support the growth of mold and development of mycotoxins, resulting in the more frequent incidence of mycotoxin contamination of food in developing countries (Agriopoulou et al. 2020). Further, virgin olive oil and extra virgin olive oil may be contaminated by mycotoxin such as aflatoxin G_1 (AFG_1) with incidence rate of 18% (Hidalgo-Ruiz et al. 2019). The available data on olive oil contamination by OTA or other AFs such as AFG_1 in the

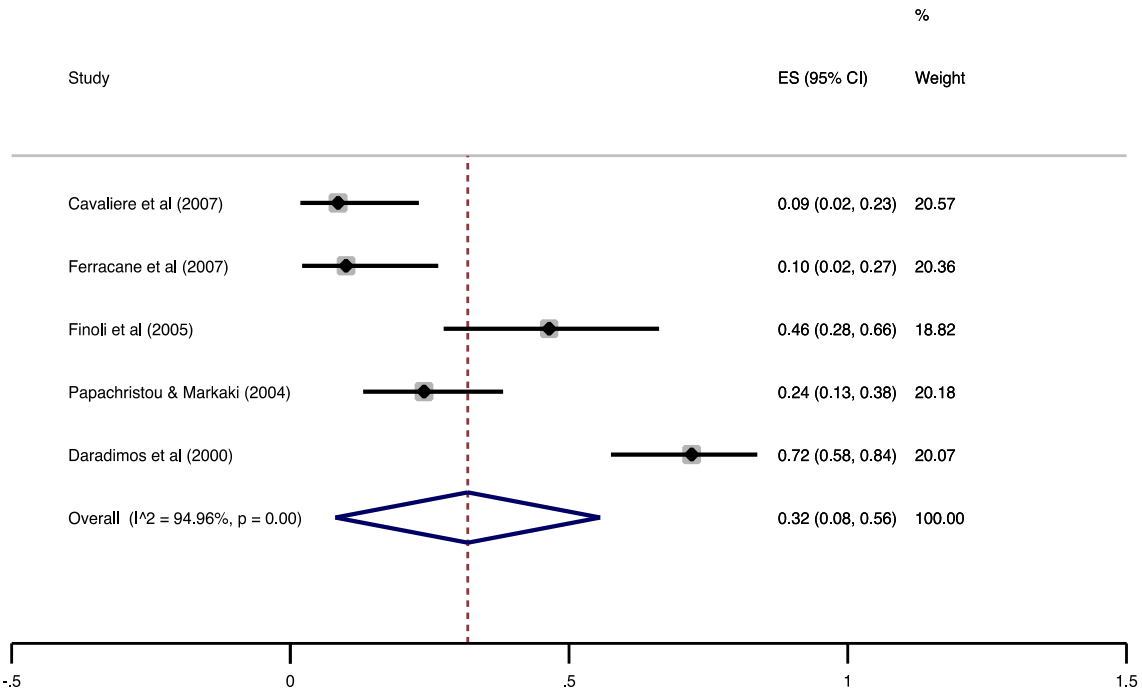

Fig. 2 Forest plot of prevalence (%) of Aflatoxin B1 in in olive oil. ES: effect size or key measure, CI: Confidence interval

literature did not meet sample size requirement for meta-analysis.

Despite of high consumption of olive oil in Mediterranean country and increasing consumption rate in the world, studies regarding contamination of olives or olive oil with mycotoxin are limited compared to the other agricultural products (Ben Rejeb et al. 2009). Also, hazard assumed as insignificant, since OTA and AFB_1, have been discovered in extra-virgin olive oil hardly or at very low concentration (Alamprese 2014). It should be noted that aflatoxin concentrations in food generally do not make an acute unfavorable effect on consumers, but continuous exposure may cause significant hazard to users (Agriopoulou et al. 2020). Recently, unrefined olive oils under the legal limit reported to have potential risk of liver cancer for adult and children (Nabizadeh et al. 2018). While olives and olive oil are a principal component in the Mediterranean diet, even low levels of contamination may cause danger to public health due to its high daily intake (Ben Rejeb et al. 2009).

Although there is considerable progress in development and validation methods of mycotoxins analysis in olive oil (Bao et al. 2010; Dridi et al. 2015; Zhao et al. 2017a, b; Xiao et al. 2018; Hidalgo-Ruiz et al. 2019; Karunarathna et al. 2019; Zhang and Xu 2019; Yu et al. 2019), there is limited researches when it comes to the occurrence of AFs and OTA with categorical data based on factors affecting the incidence of mycotoxins in olive oils.

It assumed that refining process will remove or reduce mycotoxins in vegetable oils (Lacoste et al. 2005; Banu and Muthumary 2010; Idris et al. 2010; Mariod and Idris 2015; Nabizadeh et al. 2018; Karunarathna et al. 2019), depends on the oil type and refining method (Banu and Muthumary 2010). Although the opposite is also true, recently contradictory results in the literature with 73% of zearalenone contamination in refined olive oil were reported, despite the probability of mycotoxin elimination in refining process (Hidalgo-Ruiz et al. 2019). To declare the effect of refining on mycotoxin elimination further studies on refined and unrefined olive oil is required. It should be considered that nutritional characteristics belong to the virgin olive oils category consumed without refining process.

It seems that more researches are required to correlate mycotoxin contamination to chemical and sensorial characterization. Acidity as one of the main quality index of olive oil could be influenced by mold growth (Finoli et al. 2005). It has been mentioned that mycotoxins have no odor and do not change the organoleptic properties (Agriopoulou et al. 2020), However, presence of fungi in virgin olive oil could be detected as negative attribute by panelist as musty flavor due to fungi growth on stored olive in humid conditions for a couple of days (IOC 2018a). This may be correlated to the presence of mycotoxins in olive oils, although there is a research gap when it comes to identifying the actual stage of olive fruit or olive oil contamination by mycotoxins (Bhat and Reddy 2017).

To guarantee consumer safety against risk of contaminants, specific attention to the level of contaminations in foods is needed. Consequently, international and national organizations set maximum residual limits (MRLs) for different contaminations. To the best of our knowledge, there is no legal limit for mycotoxins in vegetable oil in international standards such as CODEX. Generally, in such standards it has been mentioned that "The products covered by this standard shall comply with the maximum levels of the general standard for contaminants and toxins in food and feed" (FAO/WHO 2015). In addition, International Olive Council (IOC) refers to MRLs established by the Codex standard for olive oil (IOC 2018b). The European Commission (EC) sets the maximum level (MRL) for different food products (2–12 μg/kg AFB_1 and 4–15 μg/kg total aflatoxins), although edible oils as well as olive oils are not particularly addressed (The Commission of the European Communities 2010). In some countries there are national standards considering MRLs for AFB_1 and total aflatoxins in food, such as United States and China (20 μg/kg) (Xia et al. 2021). There are limited countries using MRL for AFB_1 monitoring in vegetable oils, such as China (< 10 μg/kg) except for corn oil and peanut oil (< 20 μg/kg), Russia (< 5 μg/kg), Morocco (< 5 μg/kg) and Kenya for total aflatoxins of B_1, B_2, G_1, G_2 (< 20 μg/kg) (Romer Labs 2012).

Establishment of the maximum residue limits for mycotoxins is based on total diet study, occurrence of mycotoxins in different foods and calculation of intake of contamination through food consumption basket in each country. However, mycotoxins may occur in low amount in edible oils like olive oil, it may become an important risk source due to its high consumption in some countries such as Mediterranean countries; consequently, risk assessment study is recommended.

Conclusion

Prevalence of aflatoxins in olive oils has been reported worldwide. Since AFB_1 is a carcinogenic and genotoxic substance, low levels of contamination can create a hazard to public health. This is of more significance since olives and olive oil are major constituents in the Mediterranean diet. As a measure of safety for human health, the need to regulate mycotoxins for edible oils is emphasized. Mycotoxin reduction and prevention management strategies before and after harvest are also essential to protect the consumers. In order to assess the risk of mycotoxins in diet, the cumulative amount of mycotoxin intake through the diet and various sources such as cereals, coffee, nuts, spices, etc. needs to be considered. Since the fact that olives and olive oil are the main parts of the Mediterranean diet, despite the low levels of aflatoxins and OTA found in some studies, overall concentrations of contamination are also required.

There are a few studies regarding occurrence and concentration of mycotoxins in olive oils based on categorical data and variables which affecting on the incidence of mycotoxins such as type of olive oils, refined or unrefined samples, country and origin of samples, organic agriculture versus traditional agriculture, packed or labeled versus unpacked olive oils. More primary studies are needed in this area based on detailed data of means, standard deviations, sample sizes, type of the olive oils from different countries and even different parts of a specific country as broad variance of daily consumption of olive oil in Mediterranean and non-Mediterranean countries. It should be pointed out that, there were some controversy or inconsistency in the results of primary researches and available reports which indicate the need for meta-analysis and subgroup analysis to reach conclusive results. Risk assessment of mycotoxins in olive oils and setting the maximum residual levels of mycotoxins in it, at least for countries with high consumption of olive oil, are also recommended.

Acknowledgements The authors acknowledge the support from the Agricultural Research, Education and Extension Organization for systematic reviews and meta-analysis studies.

Author contributions FS: Conceptualization; data curation; formal analysis; methodology; resources; software; supervision; validation; visualization; Writing—original draft; writing—review and editing. AR: Methodology; resources; software; validation, visualization; writing—review and editing. ZPV: Data curation, software, supervision, writing—review and editing.

Funding None.

Data availability All data generated or analyzed during this study are included in this manuscript.

Code availability Not Applicable.

Declarations

Conflict of interest The authors declare no conflict of interests.

Ethical approval Not Applicable.

Consent to participate All authors have read and approved the manuscript and agree with its submission to Journal of Food Science and Technology. If this manuscript accepted, it will not be published elsewhere in the same form, in English or in any other language. The corresponding author is undertaken to review at least three manuscripts related to the olive oil quality and safety and also systematic review and meta-analysis in food science, which submitted to Journal of Food Science and Technology.

Consent for publication Authors confirm that this work is original and has not been previously published, and is not currently under consideration for publication elsewhere.

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