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

Forough Shavakhi¹ ∙ Anosheh Rahmani² ∙ Zahra Piravi-Vanak³

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 ∙ Aflatoxin B_1
B1, aflB1, AFB1 ∙ Aflatoxin G_1
AFG_1 ∙ Aflatoxins
AFs, aflas, afls, AFS, AF ∙ CI
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

¹ Agricultural Engineering Research Institute, Agricultural Research, Education and Extension Organization (AREEEO), P.O. Box: 31585-845, Karaj, Iran
² Department of Food, Halal and Agricultural Products, Food Technology and Agricultural Products Research Center, Standard Research Institute (SRI), Karaj, Iran
³ Food Technology and Agricultural Products Research Center, Standard Research Institute (SRI), Karaj, Iran
**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 (B1, B2, G1, and G2) of 20 occur naturally in contaminated plant products (Cavaliere et al. 2007). Aflatoxin B1 (AFB1) 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 AFB1 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). AFB1 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; Gümüş 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 AFB1 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 AFB1 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(“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(AF) OR 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 = (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 afsls[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). 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 AFB1 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 AFB1 analysis were acceptable (d) There was no language limitation. Disagreements between two authors were resolved by consensus strategy. Selection of AFB1 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).
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 AFB₁ in olive oil with weighing model of DerSimonian–Laired or D+L (DerSimonian and Kacker 2007). If occurrence of AFB₁ was not available in the research, it was calculated based on the related raw data. According to the positive quantity of reported AFB₁ 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

Fig. 1 PRISMA flow diagram of the selection process
| 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(0.04), 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 = 2 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), VOO 3 (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 Morocco 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 | $56 \times 10^{-3}$ | – |
| 9  | Daradimos     | 2000         | Greece  | 50                       | Greek oil company | VOO | B1 | B1 = 36 | HPLC-FD | $2.8 \times 10^{-3}$ | – |

1 = Extra virgin olive oil, 2 = Olive Oil, 3 = Virgin Olive Oil
Exact Method. Assuming that prevalence of AFB1 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 AFB1 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 AFB1 contamination were 8% (95% CI 2–27%), 13% (95% CI 28–66%), 24% (95% CI 13–38%) respectively (Daradimos et al.2006). Conversely, OTA was reported in olives from different origins, varieties (black or green), environments which support the mold growth, mycotoxin contamination of food in developing countries (Duarte 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). 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). Virgin olive oil and extra virgin olive oil may be contaminated by mycotoxin such as aflatoxin G1 (AFG1) with incidence rate of 18% (Hidalgo-Ruiz et al. 2019). The available data on olive oil contamination by OTA or other AFs such as AFG1 in the
The literature did not meet the sample size requirement for meta-analysis.

Despite high consumption of olive oil in Mediterranean countries and increasing consumption rates in the world, studies regarding contamination of olives or olive oil with mycotoxins are limited compared to other agricultural products (Ben Rejeb et al. 2009). Also, the hazard assumed as insignificant, since OTA and AFB, 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 research 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 was assumed that refining process will remove or reduce mycotoxins in vegetable oils (Lacoste et al. 2005; Banu and Muthumary 2010; Idris et al. 2010; Marid and Idris 2015; Nabizadeh et al. 2018; Karunarathna et al. 2019), depending 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).

### Fig. 2

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

| Study                      | ES (95% CI)      | Weight |
|----------------------------|------------------|--------|
| Cavallero et al. (2007)    | 0.09 (0.02, 0.23) | 20.57  |
| Ferracane et al. (2007)    | 0.10 (0.02, 0.27) | 20.36  |
| Finoli et al. (2005)       | 0.46 (0.28, 0.66) | 18.82  |
| Papachristou & Markaki (2004) | 0.24 (0.13, 0.38) | 20.18  |
| Daradimos et al. (2000)    | 0.72 (0.58, 0.84) | 20.07  |
| Overall (I^2 = 94.96%, p = 0.00) | 0.32 (0.08, 0.56) | 100.00 |
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.

References

Afzali D, Ghanbarian M, Mostafavi A et al (2012) A novel method for high preconcentration of ultra trace amounts of B1, B2, G1 and G2 aflatoxins in edible oils by dispersive liquid-liquid microextraction after immunoaffinity column clean-up. J Chromatogr A 1247:35–41. https://doi.org/10.1016/j.chroma.2012.05.051

Agriopoulou S, Stamatakopoulou E, Varzakas T (2020) Advances in occurrence, importance, and mycotoxicosis control strategies: Prevention and detoxification in foods. Foods 9:137

Alamprese C (2014) Extra-virgin olive oil contaminants. In: The extra-virgin olive oil handbook. pp 75–85

Alkhaitib A (2020) Antiviral functional foods and exercise lifestyle prevention of coronavirus. Nutrients 12:1–17

Banu N, Muthumary J (2010) Aflatoxin B1 contamination in black olives in brine. Int J Food Microbiol 32:217–223. https://doi.org/10.3724/SP.J.1123.2019.01003

Ben Rejeb I, Arduini F, Arvinte A et al (2009) Development of an electrochemical assay for AFBI detection in olive oil. Biosens Bioelectron 24:1962–1968. https://doi.org/10.1016/j.bios.2008.10.002

Bhat R, Reddy KRN (2017) Challenges and issues concerning mycotoxins contamination in oil seeds and their edible oils: Updates from last decade. Food Chem 215:425–437

Bordin K, Sawada MM, da Rodrigues CE et al (2014) Incidence of aflatoxins in oil seeds and possible transfer to oil: a review. Food Eng Rev 6:20–28

Bramer WM, Rethlefsen ML, Kleijnen J, Franco OH (2017) Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. Syst Rev. https://doi.org/10.1186/s13643-017-0644-y

Campagnollo FB, Mosauvi Khaneghah A, Borges LL et al (2020) In vitro and in vivo capacity of yeast-based products to bind to aflatoxins B1 and M1 in media and foodstuffs: a systematic review and meta-analysis. Food Res Int 137:109505. https://doi.org/10.1016/j.foodres.2020.109505

Cavaliere C, Foglia P, Guarino C et al (2007) Determination of aflatoxin B1 in olive oil by liquid chromatography-tandem mass spectrometry. Anal Chim Acta 596:141–148. https://doi.org/10.1016/j.aca.2007.05.055

Daradimos E, Marpaki P, Kouparis M (2000) Evaluation and validation of two fluorometric HPLC methods for the determination of aflatoxin B1 in olive oil. Food Addit Contam 17:65–73. https://doi.org/10.1080/026652030283603

DerSimonian R, Kacker R (2007) Random-effects model for meta-analysis of clinical trials: an update. Contemp Clin Trials 28:105–114. https://doi.org/10.1016/j.cct.2006.04.004

Dridi F, Marrakech I, Gargouri M et al (2015) Thermolysin entrapped in a gold nanoparticles/polymer composite for direct and sensitive conductometric biosensing of ochratoxin A in olive oil. Sensors Actuators, B Chem 221:480–490. https://doi.org/10.1016/j.snb.2015.06.120

Duarte SC, Pena A, Lino CM (2009) Ochratoxin A non-conventional exposure sources: a review. Microchem J 93:115–120

Eltem R (1996) Growth and aflatoxin B1 production on olives and olive paste by moulds isolated from “Turkish-style” natural black olives in brine. Int J Food Microbiol 32:217–223. https://doi.org/10.1016/1605-01115-4

Fakhri Y, Ghorbani R, Taghavi M et al (2019) Concentration and prevalence of aflatoxin M1 in human breast milk in Iran: systematic review, meta-analysis, and carcinogenic risk assessment: a review. J Food Prot 82:785–795. https://doi.org/10.4315/0362-028X.JFP-18-367

FAO/WHO 1995 (2015) general standard for contaminants and toxins in food and feed (CODEX STAN 193-1995) Adopted in 1995 Revised in 1997, 2006, 2008, 2009 Amended in 2010, 2012, 2013, 2014, 2015. Gen Stand Contamin Toxins Food Addit Codex Stan 193-1995) 1:13–34

Farhadi A, Fakhri Y, Kachuei R et al (2021) Prevalence and concentration of fumonisins in cereal-based foods: a global systematic review and meta-analysis study. Environ Sci Pollut Res 28:20998

Ferracane R, Tafuri A, Logieco A et al (2007) Simultaneous determination of aflatoxin B1 and ochratoxin A and their natural occurrence in Mediterranean virgin olive oil. Food Addit Contamin 24:173–180. https://doi.org/10.1080/026520300283603

Finoli C, Vecchio A, Planeta D (2005) Mycotoxin occurrence in extra virgin olive oils and in olives. Ind Aliment 44:506–514

Ghitakou S, Koutras K, Kanellou E, Markaki P (2006) Study of aflatoxin B1 and ochratoxin A production by natural microflora and Aspergillus parasiticus in black and green olives of Greek origin. Food Microbiol 23:612–621. https://doi.org/10.1016/j.fm.2005.12.008

Gumus O, Yasar E, Gumus ZP, Ertas H (2020) Comparison of different classification algorithms to identify geographic origins of olive oils. J Food Sci Technol 57:1535–1543. https://doi.org/10.1007/s13197-019-04189-4

Hidalgo-Ruiz JL, Romero-González R, Martínez Vidal JL, Garrido Frenich A (2019) A rapid method for the determination of mycotoxins in edible vegetable oils by ultra-high performance liquid chromatography-tandem mass spectrometry. Food Chem 288:22–28. https://doi.org/10.1016/j.foodchem.2019.03.003

Higgins JPT, Thompson SG (2002) Quantifying heterogeneity in a meta-analysis. Stat Med 21:1539–1558. https://doi.org/10.1002/sim.1186

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans (2012) Chemical agents and related occupations. IARC Monogr Eval Carcinog Risks Hum 100:9–562

Idris YMA, Mariod AA, Elhouri IA, Mohamed AA (2010) Determination of aflatoxin levels in Sudanese edible oils. Food Chem Toxicol 48:2539–2541. https://doi.org/10.1016/j.fct.2010.05.021

IOC (2018a) Sensory analysis of olive oil: method for the organoleptic assessment of virgin olive oil. Int Olive Coun

IOC (2018b) International trade standard applying to olive oils and olive-pomace oils. Coi/T15/Nc

Karunarathna NB, Fernando CJ, Munasinghe DMS, Fernando R (2019) Occurrence of aflatoxin in edible vegetable oils in Sri Lanka. Food Control 101:97–103. https://doi.org/10.1016/j.foodcont.2019.02.017

Romer Labs (2012) Mycotoxin regulations. http://www.romerlabs.com/en/knowledge/mycotoxin-regulations/regulations-usa/.

Accessed 27 Apr 2021

Lacoste F, Lechat H, Pages X et al (2005) Food safety in the field of vegetable oils: from monitoring of undesirable compounds to survey plans. OCL Ol Corps Gras Lipides 12:372–377

Li S, Li X, Zhang Q (2019) Advances in the development of detection techniques for mycotoxins in vegetable oil. Chin J Chromatogr 37:569–580. https://doi.org/10.3724/SP.J.1123.2019.01003
Liu Y, Hu A, Ma Y, Wen Y (2017) Quality and safety control of the processing of vegetable oilseed and edible oil. J Chin Cereal Oils Assoc 32:177–185

Ma F, Wu R, Li P, Yu L (2016) Analytical approaches for measuring pesticides, mycotoxins and heavy metals in vegetable oils: A review. Eur J Lipid Sci Technol 118:339–352

Mahato DK, Lee KE, Kamle M et al (2019) Aflatoxins in food and feed: an overview on prevalence, detection and control strategies. Front Microbiol 10:2266

Mariod AA, Idris YMA (2015) Aflatoxin B1 levels in groundnut and sunflower oils in different Sudanese states. Food Addit Contam Part B Surveill 8:266–270. https://doi.org/10.1080/19393210.2015.1082511

Markaki P (2010) Occurrence of aflatoxin B1 in the Greek virgin olive oil: estimation of the daily exposure. In: Olives and olive oil in health and disease prevention. pp 407–414

Moher D, Liberati A, Tetzlaff J et al (2009) Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med 6:e1000697

Mousavi Khaneghah A, Farhadi A, Nematollahi A et al (2020) A systematic review and meta-analysis to investigate the concentration and prevalence of trichothecenes in the cereal-based food. Trends Food Sci Technol 102:193–202

Nabizadeh S, Shariatifar N, Shokoohi E et al (2018) Prevalence and probabilistic health risk assessment of aflatoxins B1, B2, G1, and G2 in Iranian edible oils. Environ Sci Pollut Res 25:35562–35570. https://doi.org/10.1007/s11356-018-3510-0

Nyaga VN, Arbyn M, Aerts M (2014) Metaprop: a Stata command to perform meta-analysis of binomial data. Arch Public Heal 72:1–10. https://doi.org/10.1186/2049-3258-72-39

Okhkhassae A, Ait-Addi E (2020) Mycotoxins in foods: a review on liquid chromatographic methods coupled to mass spectrometry and their experimental designs. Crit Rev Food Sci Nutr. https://doi.org/10.1080/10408398.2020.1856034

Özcan MM, Findik S, Alijuhaimi F et al (2019) The effect of harvest time and varieties on total phenolics, antioxidant activity and phenolic compounds of olive fruit and leaves. J Food Sci Technol 56:2373–2385. https://doi.org/10.1007/s13197-019-03650-8

Papachristou A, Markaki P (2004) Determination of ochratoxin A in virgin olive oils of Greek origin by immunofinity column clean-up and high-performance liquid chromatography. Food Addit Contam 21:85–92. https://doi.org/10.1080/02652030310001632547

Rahmani A, Jinap S, Soleimany F (2009) Quantitative and qualitative analysis of mycotoxins. Compr Rev Food Sci Food Saf. https://doi.org/10.1111/j.1541-4337.2009.00079.x

Rousos S, Zaoula N, Salih G et al (2006) Characterization of filamentous fungi isolated from Moroccan olive and olive cake: Toxinogenic potential of Aspergillus strains. Mol Nutr Food Res 50:500–506

Sarmast E, Fallah AA, Jafari T, Mousavi Khaneghah A (2021) Occurrence and fate of mycotoxins in cereals and cereal-based products: a narrative review of systematic reviews and meta-analyses studies. Curr Opin Food Sci 39:68–75

Selvaraj JN, Wang Y, Zhou L et al (2015) Recent mycotoxin survey data and advanced mycotoxin detection techniques reported from China: a review. Food Addit Contam Part A Chem Anal Control Expo Risk Assess 32:440–452. https://doi.org/10.1080/19440049.2015.1010185

Shavakhi F, Rahmani A, Moradi P (2021) Characterization of Iranian olive oils based on biophenolic minor polar compounds and their contribution to organoleptic properties. Yüzüncü Yıl Üniversitesi Tarım Bilim Derg 31:365–376. https://doi.org/10.29133/YYUTBD.880140

Tantaoui-Elaraki A, Riba A, Ouesslati S, Zinedine A (2018) Toxigenic fungi and mycotoxin occurrence and prevention in food and feed in northern Africa: a review. World Mycotoxin J 11:385–400

The Commission of the European Communities (2010) Commission Regulation (EU) No 165/2010 of 26 February 2010 amending Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs as regards aflatoxins. Off J Eur Union L 50(8):5

Xia Q, Du Z, Lin D et al (2021) Review on contaminants in edible oil and analytical technologies. Oil Crop Sci 6:23–27. https://doi.org/10.1016/j.ocsoci.2021.02.001

Xiao MW, Bai XL, Liu YM et al (2018) Simultaneous determination of trace Aflatoxin B1 and Ochratoxin A by aptamer-based microchip capillary electrophoresis in food samples. J Chromatogr A 1569:222–228. https://doi.org/10.1016/j.chroma.2018.07.051

Yu X, Li Z, Zhao M et al (2019) Quantification of aflatoxin B1 in vegetable oils using low temperature clean-up followed by immuno-magnetic solid phase extraction. Food Chem 275:390–396. https://doi.org/10.1016/j.foodchem.2018.09.132

Zhang K, Xu D (2019) Application of stable isotope dilution and liquid chromatography tandem mass spectrometry for multi-mycotoxin analysis in edible oils. J AOAC Int 102:1651–1656

Zhao H, Chen X, Shen C, Qu B (2017a) Determination of 16 mycotoxins in vegetable oils using a QuEChERS method combined with high-performance liquid chromatography-tandem mass spectrometry. Food Addit Contam Part A Chem Anal Control Expo Risk Assess 34:255–264. https://doi.org/10.1080/19440049.2016.1266096

Zhao Y, Wan LH, Bai XL et al (2017b) Quantification of mycotoxins in vegetable oil by UPLC-MS/MS after magnetic solid-phase extraction. Food Addit Contam Part A Chem Anal Control Expo Risk Assess 34:1201–1210. https://doi.org/10.1080/19440049.2017.1319074

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.