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Food fraud: Assessing fraud vulnerability in the extra virgin olive oil supply chain

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ABSTRACT

As a high value commodity on the market, extra virgin olive oil (EVOO) is a suitable target for fraudsters. To understand differences in perceived fraud vulnerability between tier groups across the EVOO supply chain and to disclose underlying factors, the perceived fraud vulnerability of 28 companies was examined using the SSAFE food fraud vulnerability assessment tool. Amongst these companies were seven olive oil producers, seven business-to-business (B2B) companies, seven food manufacturers and seven retailers. The similarities and differences in perceived fraud vulnerabilities according to group characteristics (the role, the scale and the location of the company) were evaluated. Non-parametric tests and multiple correspondence analysis were applied for data exploration. An in-depth fraud vulnerability assessment of the EVOO supply chain was provided. Eight fraud factors related to opportunities and motivations scored high in the supply chain indicating their importance as fraud drivers and enablers. Four factors related to control measures are perceived as greatest vulnerability in the EVOO supply chain. Then, the vulnerability to fraud in the EVOO supply chain across all actors is perceived as high level on average. In decreasing contribution to the overall perceived fraud vulnerability, the fraud factor categories were ranked as follow: technical opportunities, a lack of managerial controls, a lack of technical controls, economic drivers, cultural and behavioural drivers, and opportunities in time and place. Among the tier groups, the retailers and B2B companies experienced higher levels of perceived vulnerability than olive oil producers and food manufacturers due to the additional vulnerability related to the opportunities in time and place, and greatest lack of control measures. Furthermore, the perceived fraud vulnerability of the company was not only determined by the tier group, but also impacted by the scale and location of the company.

1. Introduction

Olive oil is the oil obtained from olive fruit after appropriate processing. The nutritional value and health benefits of olive oil make it a valuable commodity and consequently it is sold at a high price on the market. Increasing prices and relatively low consumer capabilities to detect inauthentic olive oil create an appealing crime opportunity for fraudsters (Food Standards Agency, 2016). Its liquid state also permits easy blending and mixing with inferior or cheaper oils (NSF, 2014). Therefore, olive oil is considered as one of the most frequently reported fraudulent commodities based on the three global food fraud databases from 2008 to 2013 (Weesepoel & van Ruth, 2015). Obviously, olive oil fraud is not a new threat as its adulteration has been reported since earlier years. In Morocco, olive oil was adulterated with lubricating oil used in jet engines, which left 10,000 people ill (Travers, 1962). While in 1981, over 20,000 people were poisoned from toxic oil syndrome that resulted from the sale of denatured rapeseed oil labelled as olive oil in Spain (Lipp, 2012; Mueller, 2011). These olive oil fraud incidents have resulted in actual public health risks.

Extra virgin olive oil (EVOO), as the premium quality olive oil, is particularly susceptible to be adulterated with cheaper vegetable oils (Jabeur et al., 2014), or lower quality olive oils (Karbasian, Givianrad, & Ramezan, 2015). Moreover, Forbes stressed that probably 80% of the Italian EVOO on the market is fraudulent commodities (Rodriguez, 2016). In recent years, many EVOO fraud incidents have been exposed (Lord, Spencer, Albanese, & Flores Elizondo, 2017). An Italian operation led to the arrest of 33 suspects who exported fake EVOO to the United States (Smith, 2017). In 2019, the Europol-coordinated

Abbreviations: B2B, business-to-business; FFVA, food fraud vulnerability assessment; EVOO, extra virgin olive oil; IOC, international olive council; MCA, multiple correspondence analysis

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Table 1
Characteristics of the 28 companies assessed in the study.

Tiers	Company scale	Company location [a]	Product
Olive oil producers	Small	Mediterranean (Spain)	EVOO (Organic) [b]
	Small	Mediterranean (Portugal)	EVOO (Organic)
	Small	Mediterranean (Portugal)	EVOO (Conventional)
	Small	Mediterranean (Greece)	EVOO (Organic)
	Small	Mediterranean (Greece)	EVOO (Conventional)
	Small	Mediterranean (France)	EVOO (Organic)
	Large	Mediterranean (Spain)	EVOO (Conventional)
B2B [c] companies	Small	The Netherlands	EVOO (Organic)
	Small	The Netherlands	EVOO (Organic)
	Small	The Netherlands	EVOO (Conventional)
	Small	The Netherlands	EVOO (Conventional)
	Small	The Netherlands	EVOO (Conventional)
	Small	The Netherlands	EVOO (Conventional)
	Small	The Netherlands	EVOO (Conventional)
Food manufacturers	Medium	The Netherlands	Crackers [d]
	Medium	The Netherlands	Tomato sauce
	Medium	The Netherlands	Pastry
	Medium	Mediterranean (Italy)	Tomato sauce
	Medium	Mediterranean (Spain)	Pastry
	Large	Mediterranean (Spain)	Pastry
	Large	Mediterranean (Spain)	Tomato sauce
Retailers	Small	The Netherlands	EVOO (Organic)
	Small	The Netherlands	EVOO (Organic)
	Small	The Netherlands	EVOO (Organic)
	Large	The Netherlands	EVOO (Organic)
	Large	The Netherlands	EVOO (Conventional)
	Large	The Netherlands	EVOO (Conventional)
	Large	The Netherlands	EVOO (Conventional)

[a] Eleven Mediterranean countries consist of five Spain, two Greece, two Portugal, one Italy and one France.
[b] EVOO refers to extra virgin olive oil, the 21 EVOO products consist of 10 organic EVOO and 11 conventional EVOO products.
[c] B2B refers to business-to-business.
[d] EVOO was used as an ingredient in the products of food manufacturers (tomato sauce, pastry and crackers).

operation arrested 20 fraudsters and seized 150,000 L of low-quality oils that had been adulterated with colorants to make them appear like EVOO (Taylor, 2019). Moreover, the risks of fraud may only be increasing due to the growing globalisation (Manning & Smith, 2015) and more competitive markets. To discern the EVOO fraud, laboratory-based analytical techniques on both targeted and non-targeted methods have been developed (Bajoub, Bendini, Fernandez-Gutierrez, & Carrasco-Pancorbo, 2018). These techniques are applied to identify the EVOO fraud incidents that have occurred and may reduce their impact but they do not contribute much to prevention of further incidents. This actually requires a shift in thinking from "identification" and "mitigation" to "risk assessment" and "prevention" to prevent future food fraud.

For preventing EVOO fraud, Lord et al. (2017) proposed a conceptual and analytical framework informed by a situational understanding of the nature of the activities and behaviours involved in the fraud in the EVOO supply chain. Additionally, the Global Food Safety Initiative (GFSI, 2017) defined food fraud vulnerability as a "susceptibility or exposure to a food fraud risk, which is regarded as a gap or deficiency that could place consumer health at risk if not addressed". Food fraud vulnerability assessment (FFVA) is employed to identify the weaknesses or flaws that creates opportunities for undesirable events (Spink, Ortega, Chen, & Wu, 2017). Several FFVA tools, including Vulnerability Assessment and Critical Control Points, NSF Fraud Protection Model (NSF, 2014), Food Fraud Mitigation Guidance (USP, 2016), Food Fraud Initial Screening Model (Spink, Moyer, & Speier-Pero, 2016), CARVER + Shock tool (FDA, 2009) and SSAFE FFVA tool (SSAFE, 2016), have been established to help companies and regulators anticipate fraud vulnerability in the food supply chain.

The free online FFVA tool, developed by the non-profit SSAFE organisation in partnership with Wageningen University, VU University Amsterdam, Price waterhouse Coopers, and food industry leaders around the world, aims to help strengthen internal controls of companies while reducing opportunities and motivations to adulterate food for economic gain (Food Safety Magazine, 2016). It has been successfully applied to assess the perceived fraud vulnerability in the spices chain (Silvis, van Ruth, van der Fels-Klerx, & Luning, 2017), the Dutch milk supply chain (Yang et al., 2019), and five other supply chains (van Ruth, Luning, Silvis, Yang, & Huisman, 2018).

EVOO fraud incidents were frequently reported (Rodriguez, 2016; Smith, 2017; Taylor, 2019). However, it is currently unknown which factors contribute to the vulnerability of this chain and whether the differences in fraud vulnerability between actors exist, if so, what the characteristics of these company are. Therefore, the aims of this study are to evaluate the perceived fraud vulnerability of tier groups (olive oil producers, business-to-business (B2B) companies, food manufacturers and retailers) in the EVOO supply chain using the SSAFE FFVA tool and to identify risk factors contributing to the perceived vulnerability. Furthermore, the relationship between the perceived fraud vulnerability and particular fraud factors on the one hand, and company characteristics on the other hand will also be examined to pinpoint weaker groups.

2. Materials and methods

2.1. Interviewed companies

Twenty-eight European companies were interviewed, seventeen of which were located in the Netherlands, and eleven in Mediterranean countries. Based on their obligation on the market, the companies were divided into four tier groups, including seven olive oil producers, seven B2B companies, seven food manufacturers and seven retailers. Among

the seven food manufacturers, EVOO is added as ingredient to tomato sauces (3), pastries (3) and crackers (1). With regard to the scale of the companies, sixteen were small scale companies (< 50 staff), five were medium scale companies (< 250 staff) and seven were large scale companies (> 250 staff). Table 1 shows the characteristics of the 28 companies. The typical roadmap of the EVOO supply chain from farm to table is presented in Supplementary Fig. S1.

2.2. Adaptation of the FFVA tool to the EVOO supply chain

Before onset of the interview, slight changes were made to the FFVA tool (Supplementary Table S1) to make it suitable for the EVOO supply chain investigation. For example, the questions related to "food counterfeiting" (Q6/7) were not considered since counterfeiting is not typical EVOO fraud type. Because B2B companies and retailers only act as an intermediary to transfer EVOO to their consumers, all the questions about the raw material and processing lines (Q2/3/8/32/33) were eliminated. Two olive oil producers produced also the olives themselves, their questions about suppliers were changed to customers. In total, there were 48 questions for olive oil producers and food manufacturers, and 43 questions for B2B companies and retailers. For group comparison, only the 43 questions were considered. Furthermore, the numbering of the questions was kept the same as the SSAFE FFVA tool to facilitate comparability between the obtained results and other studies that used the same tool.

2.3. Data collection

Twenty-eight companies carried out the same food fraud vulnerability assessment using the SSAFE FFVA tool (SSAFE, 2016). The adapted questionnaires were sent to the interviewees in advance to prepare the respondents for the face-to-face interviews (11 participants), skype interviews (2 participants), and telephone interviews (5 participants). The duration of these interviews was between 1 and 1.5 h each. During the interview, the interviewer asked the questions, explained the questions if necessary and recorded answers and extra explanations given by interviewees. For the other ten interviews, the questionnaire and an explanation of the questionnaire were sent to the interviewees through email, and a 10-min telephone interview was conducted for cases where the interviewee requested additional explanations for certain questions.

2.4. Statistical analyses

2.4.1. Frequency calculation

Three descriptions are provided to each question (SSAFE, 2016), and the three descriptions are converted into low, medium and high vulnerability level, and are represented by a score of 1, 2 and 3, respectively. Therefore, the low-medium-high vulnerability frequencies were calculated from the answers of interviewees for 48 fraud factors (43 factors were answered by 28 interviewees, and 5 factors were answered by 14 interviewees), for the three key elements (opportunities, Q1-11; motivations, Q12-31; control measures, Q32-50), and for the six fraud factor categories (technical opportunities, Q1-5; opportunities in time and place, Q8-11; economic drivers, Q12-14, Q19-20,Q26, Q30-31; cultural and behavioural drivers, Q15-18, Q21-25, Q28-29; technical controls, Q32-37, Q42-44, Q50; managerial controls, Q38-41, Q45-49). Afterwards, these three types of frequencies were calculated for the four tier groups (olive oil producers, B2B companies, food manufacturers and retailers).

The frequency of perceived vulnerability levels for each fraud factor/key element/fraud factor category (Fi) was determined by Eq. (1):

$$Fi = \frac{Sij}{Gj} \quad (1)$$

where Fi is the frequency of score i (i = 1, 2, 3), Sij is the number of observations which get score i in group j (j = 43 or 48 individual questions, three individual key elements and six individual fraud factor categories), and Gj is the total number of observations in group j.

2.4.2. Univariate analysis

Non-parametric Kruskal-Wallis tests were applied for group comparisons due to the ordinal data in this study. The pairwise comparisons were carried out using the Mann-Whitney U tests. Mean ranks were applied to compare the perceived fraud vulnerability of the factors between groups. The higher the mean rank value, the higher the perceived fraud vulnerability. These data analysis methods were performed using SPSS statistic 23 software (IBM, Chicago, IL, USA).

2.4.3. Cluster analysis

The score data were subjected to multiple correspondence analysis (MCA) to investigate the association between groups. This was performed using R 3.4.3 software (R Foundation for Statistical Computing, Vienna, Austria).

3. Results and discussion

3.1. Descriptive exploration

3.1.1. Degree of perceived fraud vulnerability of the EVOO supply chain

Perceived fraud vulnerability is dependent on the opportunities and motivations of fraudsters to commit fraud, as well as the presence or lack of suitable food fraud control measures (van Ruth, Huisman, & Luning, 2017). Therefore, these three key elements were assessed to identify the perceived fraud vulnerability of the EVOO supply chain. The frequencies of the different answering options cumulated for the key elements and reflecting low, medium and high perceived vulnerability are presented as green, orange and red bars, respectively, in Fig. 1. The frequencies of individual questions are presented in Fig. 2. The more prevalent the red (high vulnerability) and orange colour (medium vulnerability), the higher the perceived vulnerability. Only 35% of all questions were rated low vulnerability (Fig. 1). The orange-red (medium-high vulnerability) colour dominates in the upper and lower parts of Fig. 2, whereas green (low vulnerability) is the predominant colour in the middle part. The results indicate that most of the factors related to the opportunities and control measures were assigned high vulnerability.

3.1.1.1. Opportunities. All factors related to the technical opportunities (Q1-5) were rated high vulnerability (orange-red > 80%). This indicates that it is perceived as easy to adulterate the EVOO. It supports the fact that liquid adulteration with another liquid is common and physically the easiest to perform (NSF, 2014). Additionally, the detection and confirmation of the EVOO fraud are difficult and require advanced laboratory analysis. The European Commission (2013) and International Olive Council (IOC, 2016) have established both laboratory analytical methods and organoleptic criteria for the EVOO characterization. Organoleptic evaluation is particularly precise and not replaceable with laboratory analysis, but it seems to lack reproducibility for commercial EVOO, which is likely due to differences in sensory sensibility between the different IOC panel labs (Circi et al., 2017). Moreover, food fraud as an intentional act is difficult to be determined, because potential adulterants are unconventional, where the current conventional detection systems are not testing food for these contaminants as they simply do not know what to test for (Djekic, Jambrak, Djugum, & Rajkovic, 2018). Therefore, technical opportunities are perceived as important drivers to commit fraud (high vulnerability), demonstrated with high frequencies of answering options reflecting medium (orange, 36%) and high (red, 53%) vulnerability (Fig. 1). On the contrary, the fraud vulnerability of opportunities in time and place is perceived as

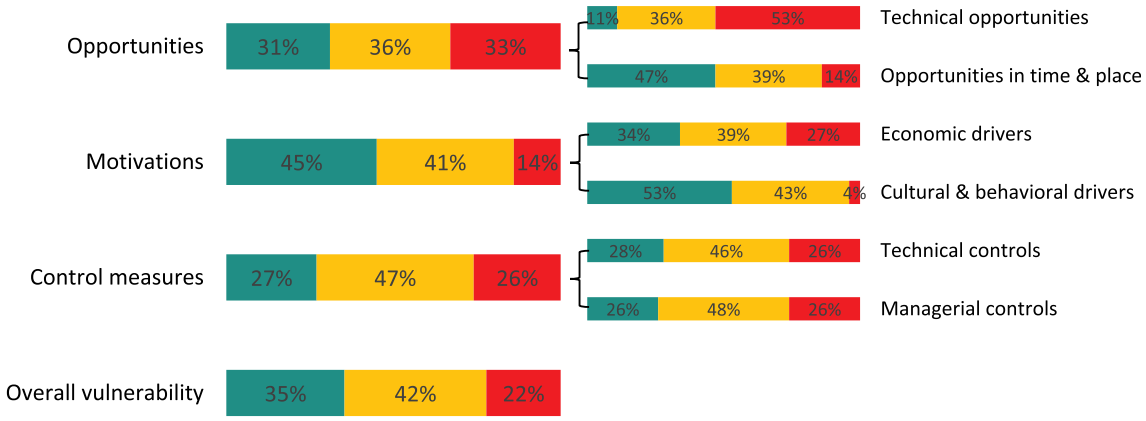

Fig. 1. Low-medium-high vulnerability frequencies of answers of 28 interviewees for the three key elements and the six fraud factor categories. Green, orange, and red describe low, medium and high vulnerability frequency, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

relatively low level (orange-red = 53%).

3.1.1.2. Motivations. Forty-five percent of the factors related to motivations are perceived as low vulnerability based on the green colour in Figs. 1 and 2. However, three factors (Q12/13/30) were assessed as high vulnerability. When the participants were asked about the supplying and pricing of raw materials (Q12), the majority (82%) commented that the price of raw materials varied depending on the harvest quantity and quality of olive fruit, as well as the geographical origin. This is in agreement with Santini, Cavicchi, Seghieri, and Bailetti (2018), who reported that the average price of EVOO in Italy grew by 74% from 2011 to 2016. The Food Standards Agency (2016) also showed that the average price of EVOO increased by nearly 10% between December 2014 and June 2015 as olive harvests in Spain and Italy suffered due to a widespread infestation of the olive tree stock by the *Xylella fastidiosa* virus. Moreover, 96% of those who were interviewed indicated that special attributes or components mainly determine the value of EVOO (Q13), such as organic characteristic, high level of antioxidants and special organoleptic properties. These findings are in accordance with a previous study which found Dutch consumers willing to pay for organic olive oil due to its production system (Kalogeras, Valchovska, Baourakis, & Kalaitzis, 2009). Another study also reported that nutrition and taste of EVOO were some of the top reasons for most US consumers' purchasing decisions (Wang, Moscatello, & Flynn, 2013). Furthermore, 96% of the respondents reported that there is a growing competition across the EVOO supply chain (Q30). This is in line with Santini et al. (2018) who stated that the olive oil business is highly competitive in Italy due to internal

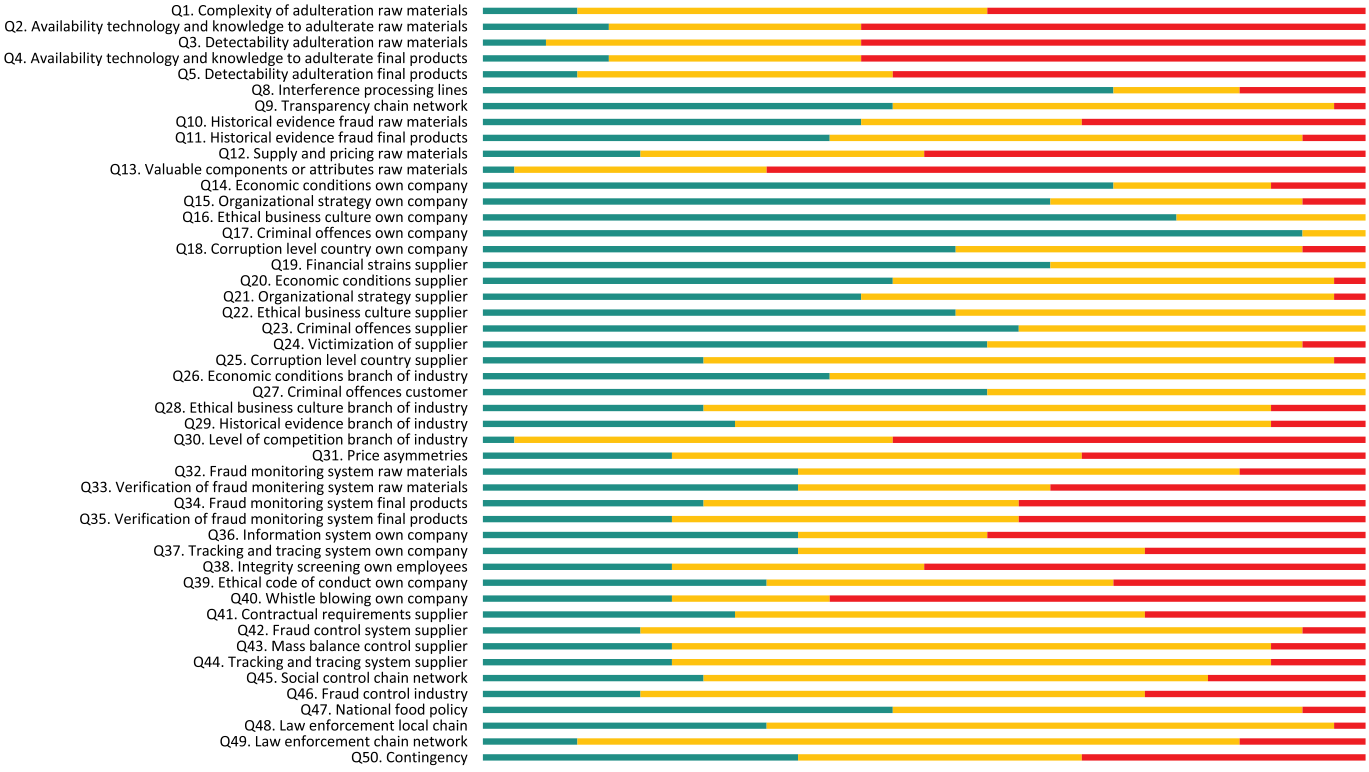

Fig. 2. Overview of low-medium-high vulnerability frequencies of answers for 48 fraud factors. Amongst these fraud factors, 43 were answered by 28 interviewees, and 5 were answered by 14 interviewees. Green, orange, and red refer to low, medium and high level of vulnerability, respectively. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

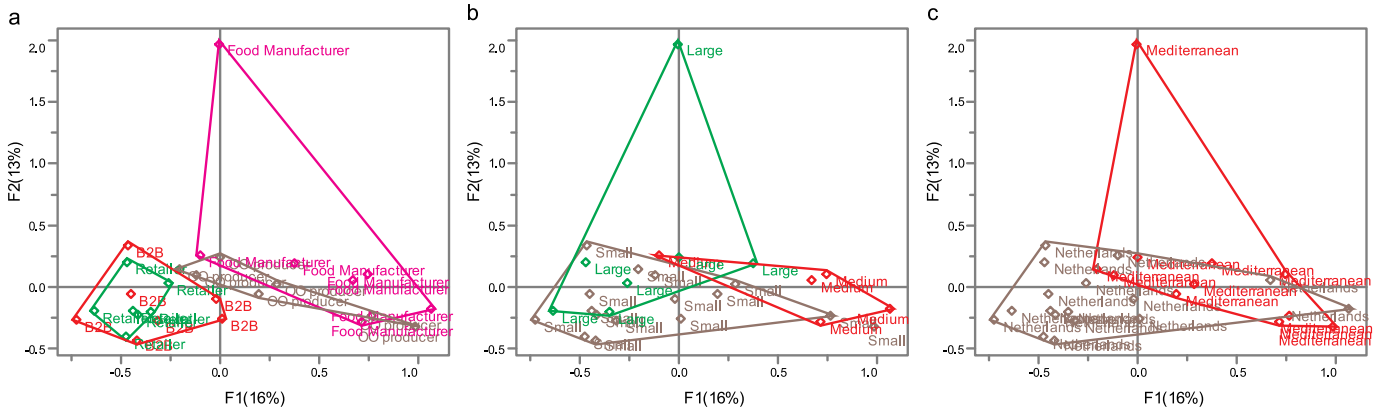

Fig. 3. Scores plots of multiple correspondence analysis on the responses of 28 interviewees a) four tier groups: olive oil producers, business-to-business (B2B) companies, food manufacturers, retailers; b) three groups according to the scale of the companies: small, medium and large; c) two groups according to the location of the companies: the Netherlands and Mediterranean countries. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

(competition between companies: price difference and oil quality) and external (the international competition: new producing countries emerging) impacts. As such, small scale companies have no competitive pricing advantage compared to other companies. Therefore, they must understand the typical features of their olive oil and establish a strong marketing strategy to promote them as unique and distinctive traits of the product to gain market share (Santini et al., 2018). These three factors are all associated with economic drivers, which supports the fact that the economically motivated adulteration is one of the major types of food fraud (Moore, Spink, & Lipp, 2012). Consequently, economic drivers (orange-red = 66%) contributed more than cultural and behavioural drivers (orange-red = 47%) to the perceived fraud vulnerability.

3.1.1.3. Control measures. Adequate control measures were merely lacking, considering the 27% of low vulnerability answers to this group of questions (Fig. 1). Control measures can be divided into technical (hard) controls and managerial (soft) controls. Hard controls refer to those aimed at the detection of fraud by generating data and actual information on the prevalence of adulterated products, while soft controls are more preventive in nature and aim at reducing opportunities and or motivations in the management system and the chain environment (van Ruth et al., 2017). In terms of the technical (hard) controls, the fraud factor related to "fraud control system of suppliers" (Q42, red-orange = 82%) was assigned to high vulnerability (Fig. 2). It indicates that most of the suppliers of the interviewed companies lacked a well-established fraud control system. More than half of the participants (16 out of 28) are small scale companies, it is reported that small companies lack any resources to implement a fraud mitigation plan (Levitt, 2016; Silvis et al., 2017). Furthermore, three factors related to the managerial (soft) controls were assigned to high vulnerability (Fig. 2). Over 80% of the participants and their suppliers lacked a specific whistle blowing system (Q40) and guidelines for fraud mitigation (Q46). A possible explanation for this might be that there exists barriers to whistleblowing. For instance, whistleblowing was viewed as treason or betrayal in Italy (Dungan, Waytz, & Young, 2015; Osterhaus & Fagan, 2007). Another possible explanation is that countries have limited or no legal frameworks to protect whistleblowers (Transparency International's Secretariat, 2013), and the whistleblowers may run the risk of being pursued and sanctioned (Motarjemi, 2018). On the other hand, this result is contrary to Soon and Manning (2017) who reported that small and medium scale companies (21 out of 28 in this study) can more readily implement a whistle blowing protocol within their organisation and with their suppliers. In addition, 89% of the interviewees stated that fraud-related enforcement practices are not aligned across the international EVOO supply chain (Q49). This is in accordance with a previous study (Corini & van der Meulen, 2018), which indicated that the enforcement of food fraud in the EU member states are different. The EU food law for the prevention of food fraud, Article 19 (European Parliament & European Union Council, 2019, p. 11), requires food business operators to withdraw and recall food products when they consider food products not to be in compliance with food safety requirements. Greece, the Netherlands and Portugal considered Article 19 applicable to the horsemeat scandal, while Ireland and Italy argued that Article 19 requirements had not been met, so they did not recall the involved food products (van der Meulen, 2015a). Taking all of the above in consideration, we can conclude that there is a great lack of food fraud control measures in the EVOO supply chain. It is likely to be related to the implementation of regulations (Havinga, 2014; van der Meulen, 2015b) and the food regulatory arrangements by companies (Havinga, 2012).

Overall, the EVOO supply chain is perceived as high vulnerable to food fraud (orange-red = 64%, Fig. 1), compared with the other food supply chains (Silvis et al., 2017; van Ruth et al., 2018; Yang et al., 2019). Eight fraud factors related to opportunities (Q1-5) and motivations (Q12/13/30) scored high in the supply chain indicating their importance as fraud drivers and enablers. Four factors (Q40/42/46/49) related to control measures are perceived as greatest lacking in the EVOO supply chain. Technical opportunities were rated the most vulnerable to fraud, followed by the lack of managerial (soft) controls, the lack of technical (hard) controls, economic drivers, cultural and behavioural drivers and opportunities in time and place.

3.1.2. Exploring clusters in perceived fraud vulnerability patterns for all companies

The FFVA data were subjected to multiple correspondence analysis (MCA) to explore the similarities in perceived fraud vulnerability patterns across the 28 companies. The first two dimensions of the MCA are shown in Fig. 3, and they explained 29% of the total variance. The scores appear to be considerably influenced by the role of the company (Fig. 3a) in the supply chain, as well as the scale (Fig. 3b) and location (Fig. 3c) of the company. In order to illustrate the association between groupings and the fraud factors, the loadings plot is shown in Fig. 4.

The retailers and B2B companies (left side along F1) are separated from the olive oil producers and food manufacturers (right side along F1) in Fig. 3a. The retailers and B2B groups show relatively high scores for opportunities, motivations, and control measures (Fig. 4). In contrast, the olive oil producers and food manufacturers are widely spread and overlap with each other in Fig. 3a, and they show relatively low scores for opportunities, motivations, and control measures (Fig. 4). The results indicate that B2B companies and retailers are generally

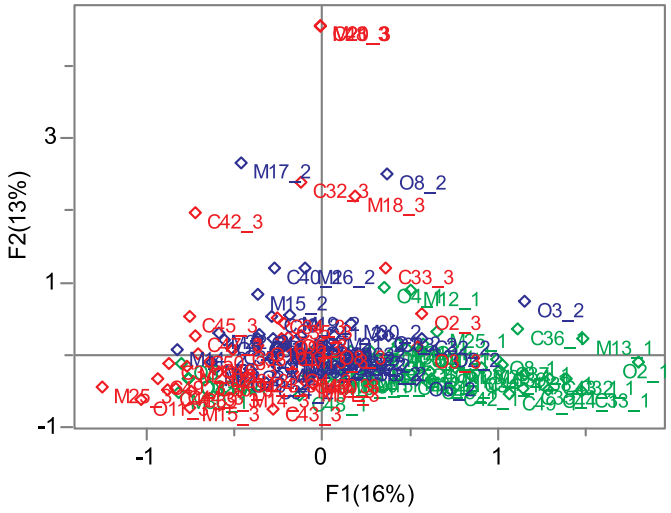

Fig. 4. Loadings plot of multiple correspondence analysis on the responses of 28 interviewees. Higher, intermediate, and lower vulnerability scores are coloured red, blue, and green, respectively. O refers to opportunities; M refers to motivations; C refers to control measures; numbers after the letter refer to question number_vulnerability level. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

more vulnerable to fraud than the other two tier groups, which means that they are perceived as more likely to be victims of fraud. For food manufacturers, the companies that produce tomato sauce are separated from the other two types of businesses (pastry and crackers) (Supplementary Fig. S2). Furthermore, the tomato sauce companies present high scores for opportunities, motivations and control measures (Supplementary Fig. S2 and S3), indicating that EVOO as an ingredient of the semi-solid product (tomato sauce) is perceived as more susceptible to be adulterated than that of the other two solid products (pastry and crackers).

Three groups of companies of different scales (size) widely spread and overlap with each other in Fig. 3b. The small scale companies grouped in the left lower quadrant and presented relatively high scores for the three key elements, large scale companies mainly grouped in the left quadrants and mainly showed medium scores. Whereas the medium scale companies grouped in the left quadrants and they appeared to be less vulnerable to fraud than the other companies (Fig. 4). The results is in line with the previous study reporting that small businesses suffer fraud more frequently than large organisations (Doody, 2009).

With regard to the location of the companies, the Netherlands group overlaps with a certain number of the Mediterranean group in Fig. 3c. Moreover, the Netherlands group show relatively high scores for the three key elements (Fig. 4). This means that companies in the Netherlands perceives themselves as more vulnerable to fraud. This higher perceived vulnerability could be due to the fact that the Dutch companies are primarily B2B companies and retailers, and they are also primarily small scale companies (Table 1). Another possible reason is that the level of food safety in the Netherlands is high, but the opportunities to commit food fraud have increased, because fraudsters are trying their utmost to remain out of the line of sight of the supervisory authority (NVWA, 2018a). furthermore, olive oil is always imported from the south of Europe, which results in a longer chain and more opportunity to commit fraud.

Additionally, the differences and similarities between the conventional and organic EVOO supply chains were investigated. It is interesting to notice that these two supply chains are widely spread and overlap with each other (Supplementary Fig. S4), which means that there is no large difference between these two supply chains. It reveals that the organic property did not contribute to additional fraud vulnerability. This finding is consistent with that of Barbieri, Bendini, Valli, and Toschi (2015) who found that organic farming information did not affect consumers' preferences for EVOO, which means that the organic property hardly affects its (added) value.

These findings indicate that the assignment to the clusters is not only due to the role of the company in the supply chain, but it is also determined by the scale and location of the company. Retailers and B2B companies have a similar perceived fraud vulnerability pattern, and they are also more vulnerable to food fraud than the other two tier groups.

3.1.3. *Exploring perceived fraud vulnerability patterns according to the role of the companies*

The low-medium-high vulnerability frequencies of answering options across the four tier groups (olive oil producers, B2B companies,

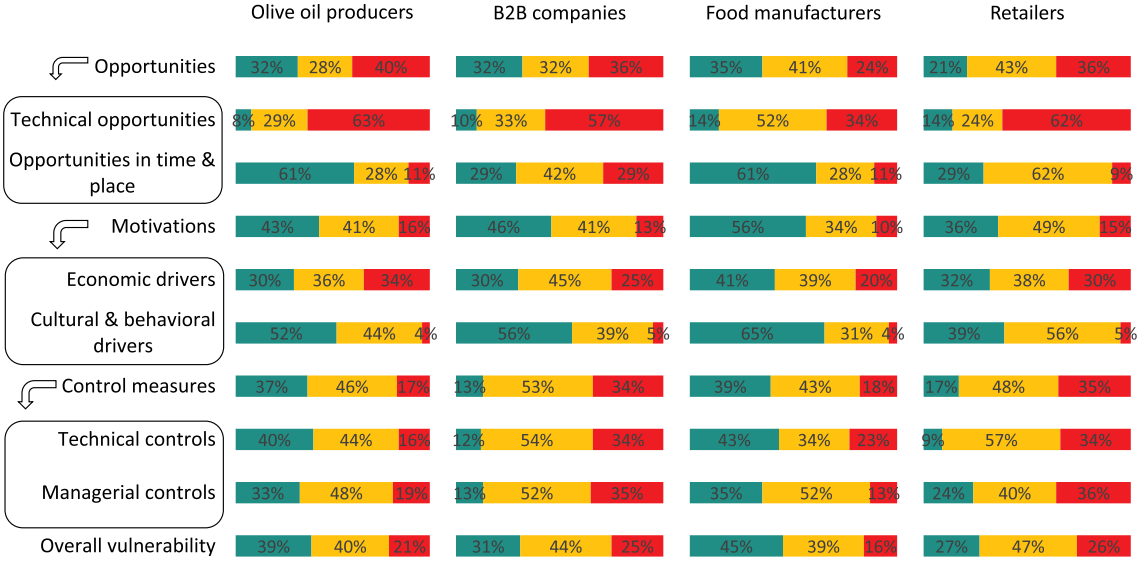

Fig. 5. Low-medium-high vulnerability frequencies of answers for the three key elements (opportunities, motivations and control measures) and the six fraud factor categories (technical opportunities, opportunities in time & place, economic drivers, cultural & behavioural drivers, technical controls and managerial controls) of the fraud vulnerability assessments for the four tier groups. Green, orange, and red refer to low, medium and high level of vulnerability, respectively. B2B refers to business-to-business. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

food manufacturers and retailers) are presented in Fig. 5. The perceived fraud vulnerability patterns of individual tier groups (Supplementary Fig. S5) are broadly similar to the overall perceived fraud vulnerability of the EVOO supply chain (Fig. 2). The upper and lower parts (opportunities and control measures) are dominated by the orange-red colour, whereas in the middle part (motivations), green is the predominant colour.

3.1.3.1. Opportunities. Technical opportunities (orange-red > 80%) were assigned to high vulnerability by the four tier groups. The B2B companies and retailers assigned opportunities in time and place (Q9/10/11) to high vulnerability (orange-red = 71%), whereas the olive oil producers and food manufacturers rated them with a low vulnerability (orange-red = 39%). The EVOO supply chain was described by the B2B companies and retailers as a complex supply chain that lacks transparency, with short-term relationships and no information exchange (Q9). According to Soon, Krzyzaniak, Shuttlewood, Smith, and Jack (2019), several sources could help companies increase the information exchange in the supply chain, including their own internal experts, guidelines provided by the different assessment methods, food safety certification bodies, professional memberships and networking with their suppliers and consumers. Furthermore, to solve traceability issues and enhance transparency, RFID and blockchain technologies (Galvez, Mejuto, & Simal-Gandara, 2018) could be applied in the supply chain. Moreover, when questioned about the historical fraud incidents (Q10/11), the olive oil producers (small scale companies) lack of access to the food fraud databases, which may result in a difficulty understand of the historic incidents (Manning & Soon, 2019). In addition, with regard to food manufacturers, compared with the frequently reported EVOO fraud incidents (Smith, 2017; Taylor, 2019), an EVOO fraud incident seldom reported for food that use EVOO as an ingredient. Consequently, B2B companies and retailers are generally more vulnerable to commit fraud. Furthermore, they are perceived more likely to be victims of fraud due to the increased opportunities in time and place.

3.1.3.2. Motivations. The factors related to economic drivers are perceived as medium-high vulnerability level by the olive oil producers, B2B companies and retailers. This is in agreement with Moore et al. (2012) who found that fraud conducted for economic gain by food producers, processors, distributors, or retailers is gaining attention and the economic motivation is the main reason for food fraud. However, food manufacturers assigned the economic drivers to the lowest vulnerability compared to the other three tier groups. A possible reason is that the addition of a small amount of EVOO as a flavour additive does not lead to large price difference. This, in turn, seems to be less motivated to commit fraud. With regard to the cultural and behavioural drivers, the retailers (orange-red = 61%) assigned these drivers to be more vulnerable to commit fraud than the other three tier groups (orange-red < 50%). This is mainly due to a lack of confidence in their suppliers (Supplementary Fig. S5). Similarly, the lack of confidence in their suppliers also appeared in the milk supply chain (Yang et al., 2019). The result reveals a weak interaction between the companies and their suppliers. Furthermore, a lack of information and knowledge sharing with other tier groups (including their suppliers) may increase food vulnerability (Soon et al., 2019). Consequently, the retailers (orange-red = 64%) assigned high vulnerability scores to fraud factors associated with motivations, followed by olive oil producers (orange-red = 57%), B2B companies (orange-red = 54%), and eventually the food manufacturers (orange-red = 44%).

3.1.3.3. Control measures. Most of the retailers and B2B companies (orange-red > 80%) stated that they predominantly lack technical controls (i.e. a fraud monitoring system, tracking and tracing system and contingency plan). Only ~60% of the responses coming from the olive oil producers and food manufacturers are in line with this statement. It is possible that the specialised trained counter-fraud staff is rarely employed within the food industry (Soon et al., 2019), which results in a weak fraud control system. Moreover, B2B companies (orange-red = 87%) were more vulnerable to commit fraud due to a lack of managerial controls. All the B2B companies in this study were small scale companies, while small businesses do not have the resources to map out the dangers of food fraud in their supply chain (Levitt, 2016; Silvis et al., 2017). Hence, a lack of resources may lead to companies being more vulnerable to fraud. Therefore, the food manufacturers (green = 39%) and olive oil producers (green = 37%) have more adequate control measures in place, followed by the retailers (green = 17%) and the B2B companies (green = 13%). This result is in line with the perceived fraud vulnerability assessment of the other supply chains (van Ruth et al., 2018).

Overall, the perceived fraud vulnerability varied between tier groups. Since B2B companies are in the middle part of the supply chain (Supplementary Fig. S1), they are also more likely to pass the potential fraud on to their customers (food manufacturers and retailers) (van Ruth et al., 2018). With regard to the medium-high vulnerability frequencies of responses of each tier group (Fig. 5), the decreasing order in perceived fraud vulnerability is retailers (orange-red = 73%), B2B companies (orange-red = 69%), olive oil producers (orange-red = 61%), and food manufacturers (orange-red = 55%). Similar to the other food supply chain (Silvis et al., 2017; van Ruth et al., 2018; Yang et al., 2019), the companies in the middle and end of the supply chain (B2B companies and retailers) are more vulnerable to fraud than the companies at the beginning of the supply chain (producers). There are two possible reasons. Firstly, because of the increased complexity of the food supply chain, when more members (the intermediaries between producers and consumers: wholesalers, distributors, and retailers) involve in the supply chain, more uncertainties accrue (Lamarre & Pergler, 2009; Ting, Tse, Ho, Chung, & Pang, 2014) and the likelihood of food fraud increases (Manning et al., 2015). Thus, B2B companies and retailers are more vulnerable to fraud. Secondly, considering their reputation and that they are easily traced through the origin place on the package, the olive oil producers and food manufacturers are more likely to present a positive outlook. Therefore, when questioned about the likelihood of being affected by food fraud, they possibly say that “It won't happen to us” (Soon et al., 2019; Weinstein, 1984).

3.2. Statistical evaluation: effect of group characteristics on perceived fraud vulnerability

3.2.1. The role of the companies

Five factors revealing significant differences (Mann-Whitney *U* test, $p < 0.05$) between tier groups are shown in Table 2, including two motivation related fraud factors (Q22, the ethical business culture of suppliers; Q24, victimization of suppliers), and three internal control measures related fraud factors (Q36, information system; Q37, tracking and tracing system; Q39, ethical code of conduct). Specifically, retailers show less confidence in their suppliers than other three tier groups (Q22/24). This is in line with previous research, which showed that external frauds occurred at their suppliers were reported more frequently than internal frauds occurred at the companies themselves due to less stringent control and preventive measures (Manning, 2016) and increased awareness of food fraud in the supply chain (Soon et al., 2019). In addition, all retailers and B2B companies showed a significantly greater lack of internal control measures (Q36/37/39) than the other two tier groups. This is in line with van Ruth et al. (2018) who reported that B2B companies (wholesalers) and retailers also lacked these internal control measures in the other food supply chains.

3.2.2. The scale of the companies

Three fraud factors showed statistically significantly different perceived vulnerability (Mann-Whitney *U* test, $p < 0.05$) between

Table 2
Fraud factors of the FFVA demonstrating significantly different perceived fraud vulnerability between tier groups.

Question number	Fraud factor	Food manufacturers (n=7)	Olive oil producers (n=7)	B2B companies (n=7)	Retailers (n=7)
Q22	Ethical business culture (supplier)	10 [c]	14 [b]	12 [bc]	22 [a]
Q24	Victimization (supplier)	9 [b]	17 [a]	14 [ab]	19 [a]
Q36	Information system (own company)	7 [a]	12 [a]	20 [b]	20 [b]
Q37	Tracking and tracing system (own company)	9 [a]	13 [a]	16 [ab]	21 [b]
Q39	Ethical code of conduct (own company)	9 [a]	12 [ab]	20 [b]	16 [ab]

[a-c] Different superscripts in a row indicate significant differences (Kruskal-Wallis tests and Mann-Whitney U tests, $p < 0.05$). Higher, intermediate, and lower vulnerability scores are coloured red, orange, and green, respectively. Refer to the online version of the article for the interpretation of the colour. FFVA refers to food fraud vulnerability assessment; B2B refers to business-to-business.

Table 3
Fraud factors of the FFVA demonstrating significantly different perceived fraud vulnerability between groups according to the scale of the company.

Question number	Fraud factor	Medium (n=5)	Small (n=16)	Large (n=7)
Q22	Ethical business culture (supplier)	8 [b]	14 [ab]	20 [a]
Q36	Information system (own company)	7 [a]	17 [b]	14 [ab]
Q47	National food policy	10 [a]	13 [a]	22 [b]

[a-b] Different superscripts in a row indicate significant differences (Kruskal-Wallis tests and Mann-Whitney U tests, $p < 0.05$). Higher, intermediate, and lower vulnerability scores are coloured red, orange, and green, respectively. FFVA refers to food fraud vulnerability assessment. Refer to the online version of the article for the interpretation of the colour.

Table 4
Fraud factors of the FFVA demonstrating significantly different perceived fraud vulnerability between groups according to the location of the company.

Question number	Fraud factor	Mediterranean countries (n=11)	The Netherlands (n=17)
Q18	Corruption level country (own company)	19 [a]	12 [b]
Q36	Information system (own company)	9 [a]	18 [b]
Q39	Ethical code of conduct (own company)	10 [a]	17 [b]

[a-b] Different superscripts in a row indicate significant differences (Mann-Whitney U tests, $p < 0.05$). Higher, and lower vulnerability scores are coloured red, and green, respectively. FFVA refers to food fraud vulnerability assessment. Refer to the online version of the article for the interpretation of the colour.

companies due to the different scale of the companies (Table 3). Small and large scale companies are perceived to be more vulnerable to fraud based on these three factors. Large scale companies (mean rank = 20) show significantly higher perceived vulnerability in the factor related to motivation (Q22, the ethical business culture of the suppliers) than medium scale companies (mean rank = 8). Since the significant difference in this factor was also found between tier groups (Table 2), both the role of the companies in the supply chain and the scale of the companies contributed to the score of this factor. While small scale companies showed greatest lack of information system on mass balance flow (Q36, mean rank = 17). Most of them stated that they only have a basic administrative system with limited information or no specific information on mass balances of incoming materials and final products. Moreover, there is no systematic analysis of mass flow data throughout the companies. In addition, large scale companies stated that there only exists a general national food policy without specific legislative requirements for food fraud mitigation (Q47, mean rank = 22). These large scale companies are primarily located in the Netherlands and the result are in agreement with the facts. The food policy of the Netherlands prescribes food safety control system in detail, but it is not specifically focusing on food fraud (NVWA, 2017; 2018b). Furthermore, the Food Confidence Task Force (The Dutch Minister for Agriculture & The Dutch Minister of Health Welfare and Sport, 2013) defined a set of criteria for quality schemes that strengthen the private safeguarding of food safety and integrity, but again it is mostly considering food safety. Although some general requirements are included in the EU General Food Law, there is no explicit framework in place to target food fraud (mitigation) in Dutch food policy. There is even no consensus on a uniform definition of food fraud in EU legislations (European Parliament, 2016; Manning et al., 2019).

3.2.3. The location of the companies

The significant differences (Mann-Whitney *U* test, $p < 0.05$) between the companies in the Netherlands and Mediterranean countries are presented in Table 4. The corruption level of the Netherlands (mean rank = 12) is significantly lower than that of the Mediterranean

countries (mean rank = 19) resulting from the motivation related fraud factor Q18. This is in agreement with the Transparency International (2018) reporting that the corruption perception index of the Netherlands (index value = 82) is higher than that of the Mediterranean countries (index value < 50). The lower the index value, the higher the corruption level. On the other hand, the corruption perception at the country level may activate the corruption perception at the industry level (Gounev & Bezlov, 2010), which in turn results in food fraud, e.g. horsemeat scandal. However, the fraud vulnerability of the Dutch companies is perceived as higher level than that of the companies in Mediterranean countries due to greatest lack of internal controls (Q36/39). Since Dutch companies are primarily B2B companies and retailers, and they are also primarily small scale companies (Table 1), the significant differences in these two fraud factors were also found between the tier groups (Table 2).

Taken together, it is evident that there are differences in perceived fraud vulnerability due to the scale and location of the companies, and those two are intertwined. Therefore, the perceived fraud vulnerability is affected by the role, the scale and the location of the companies. In addition, B2B companies and retailers are all located in the Netherlands, whereas the olive oil producers are located in Mediterranean countries. This intertwining affects the results, but are factual when it comes to olive oil producers. There are simply no olive trees growing in the Netherlands. However, in future research, B2B companies and retailers in the south of Europe could be examined as well.

4. Conclusions and outlook

An in-depth perceived fraud vulnerability assessment of the EVOO supply chain was provided to understand the differences in perceived fraud vulnerability between tier groups. Eight fraud factors related to opportunities (Q1-5) and motivations (Q12/13/30) scored high in the supply chain indicating their importance as fraud drivers and enablers. Four fraud factors (Q40/42/46/49) related to control measures are perceived as greatest lacking in the EVOO supply chain. Furthermore, the perceived fraud vulnerability varied between tier groups. The decreasing order in perceived fraud vulnerability is: retailers, B2B companies, olive oil producers and food manufacturers. The retailers and B2B companies are accompanied by additional vulnerability due to opportunities in time and place and greatest lack of control measures. In addition, the variations of the perceived fraud vulnerability across the EVOO supply chain were determined not only by the role of the company, but also by the scale and the location of the company.

The knowledge from the current study can be used to pinpoint the weaker spots in the chain in order to develop and implement data-driven control measures. For instance, once the weaker spots were identified, then the potential situational mechanisms for reducing and preventing food fraud in the EVOO supply chain could be generated (Lord et al., 2017). For individual actors, it is recommended to select suppliers with care, be part of a transparent chain and implement adequate control measures in order to reduce fraud vulnerability. Future research could focus on an extension of actors. This could concern a larger diversity of countries including those from outside the EU, but also a greater variety of nodes in the chain, e.g. olive growers and food service industry actors.

Author contributions

Jing Yan: Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

Sara W. Erasmus: Performed the analysis; Wrote the paper.

Miguel Aguilera Toro: Collected the data; Contributed data or analysis tools; Performed the analysis; Edited the manuscript.

Haixin Huang: Collected the data; Contributed data or analysis tools; Performed the analysis; Edited the manuscript.

Saskia M. van Ruth: Conceived and designed the analysis; Contributed data or analysis tools; Performed the analysis; Wrote the paper

Declaration of competing interest

The authors declare that there is no conflict of interest.

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Appendix A. Supplementary data

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