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FUNGAL INFECTION OF STORED ARABICA COFFEE (*Coffea arabica*) BEANS IN SOUTH SULAWESI PROVINCE, INDONESIA

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ABSTRACT

Indonesia is the world's fourth-largest coffee producer after Brazil, Vietnam, and Columbia, in which one of its well-known coffee originates from the Toraja region, South Sulawesi. As such, Indonesia has to compete with these countries in producing good quality coffee beans. Consequently, this research aimed (a) to obtain information on the postharvest handling methods of Arabica coffee (*C. arabica*) beans in Tana Toraja Regency, North Toraja Regency, and Makassar Municipality, Indonesia, and (b) to investigate the occurrence of fungi (including ochratoxin A producing fungi) in stored Arabica coffee beans collected from various stages of the delivery chain. The data collection process included surveys, interviews, and sample collections conducted in May and July 2016 at each level of the delivery chain. The moisture content (MC) and the physical quality of the beans were also measured to determine its quality. Sixty-four (64) coffee bean samples were collected, consisting of 27 samples from the farmers, 15 samples from the collectors, 13 samples from the traders, and 9 samples from the exporters. The results showed that the moisture contents of coffee beans collected from the farmers and bean collectors (42.5%) were significantly higher than the maximum tolerable limit determined by the Indonesian National Standard (SNI) (13%), while the MC of the beans from the traders and exporters (9.7-10.9%) was significantly lower. Based on the total defective values, coffee beans from the farmers had more diverse grades (1-6) than those at other levels. *Penicillium citrinum* was the dominant fungus found in those beans collected from the farmers, collectors, and traders, while *Aspergillus niger* was the dominant fungus found in those beans from the exporters. At trader level, 46% of the samples were infected by *Aspergillus ochraceus* and *A. niger*, which are known as ochratoxin A (OTA) producing fungi. At exporter level, 44% of the samples were infected by *A. ochraceus*, while 78% of the samples were infected by *A. niger*. Thus, the postharvest handling methods conducted especially by farmers and collectors of Arabica coffee beans should be improved to reduce the moisture content and to increase the grade quality of the coffee beans.

Keywords: Arabica coffee beans, *Aspergillus niger*, *A. ochraceus*, ochratoxin, quality

INTRODUCTION

Around 70 countries worldwide are coffee beans producers; with the overwhelming majority of the supply coming from the developing countries, like Brazil, Vietnam, Colombia, Indonesia, and Ethiopia (Walton 2018). Indonesia is the fourth-largest producer in the world, cultivating two kinds of coffee, namely; Robusta coffee (*Coffea canephora*) and Arabica coffee (*C. arabica*), and the second in Southeast Asia after Vietnam. Robusta and Arabica coffee contribute about 83% and 17%, respectively, of the total coffee production in Indonesia (GAEKI 2018). Tana Toraja Regency in South Sulawesi Province, Indonesia is one of the producers of Arabica coffee (Tana Toraja coffee) that is exported to sixteen countries which include among others, Belgium, the United States of America, and Japan (Hendrawan 2014).

As one of the largest producers, Indonesia, competes with other countries in producing good quality coffee beans. Hence, stringent rules must be imposed to maintain the quality of exported beans. However, not many people

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have sufficient skills in tackling problems related to the postharvest handling of these coffee beans.

During storage, coffee beans could be infested by insects, microorganisms, mites, and rats. Among microorganisms, fungi are the most dominant cause of deterioration in stored grains or seeds. Fungal infection in grains can cause discoloration, musty odor, weight loss, reduction in nutritional contents, and mycotoxin contamination.

Unlike Robusta coffee beans (Dharmaputra *et al.* 2000; Yani 2008; Nugroho *et al.* 2013), little is known about fungal infection (including ochratoxin-producing fungi) in Arabica coffee beans in Indonesia.

Ochratoxin A (OTA) contamination in coffee beans has recently become very important as some consumer countries have imposed their maximum tolerable limits (MTL). OTA is a potent nephrotoxic mycotoxin that has been linked to kidney problems in both livestock and human populations (Cabañes *et al.* 2010). It also has carcinogenic, genotoxic, and immunotoxic properties. OTA has been reported in temperate and tropical countries to naturally occur mainly on cereals and their products. However, it is also found in a variety of common foods and beverages, including bread, beer, chocolate, coffee, dried fruits, grape juice, pork, poultry, and wine, among others. In tropical regions, OTA is mainly produced by *Aspergillus carbonarius*, *A. niger,* and *A. ochraceus*, while in sub-tropical regions, it is produced by *Penicillium verrucosum* (Bui-Klimke & Wu 2015).

In order to monitor the storage procedures of the coffee beans, this study aimed to: (1) to obtain information on postharvest handling methods of Arabica coffee beans (*C. arabica*) conducted by farmers, collectors, traders, and exporters and (2) to investigate the degree of fungal infection (including OTA-producing fungi) in stored Arabica coffee beans collected from various stages of the delivery chain in Tana Toraja and North Toraja Regencies, and Makassar Municipality, South Sulawesi Province, Indonesia. The moisture content (MC) and physical quality (based on defective value) of the coffee beans were also determined because these properties are known to influence fungal infection.

MATERIALS AND METHODS

Time and Location of the Study

Surveys, interviews and sample collection of the Arabica coffee beans were conducted at the farmer, collector, trader and exporter levels in the South Sulawesi Province, particularly, Tana Toraja Regency, North Toraja Regency, and Makassar Municipality, in May and July 2016. These regencies were selected because they produce large quantities of Arabica coffee beans and Makassar city is the main port for exporting Arabica coffee beans.

Interviews Using Questionnaires

Interviews using structured questionnaires were conducted during the surveys to collect information on coffee bean postharvest handling methods at different stages of the delivery chain, specifically at the farmer, collector, trader, and exporter levels. Data were collected from interviews with respondents using the purposive sampling method. The questionnaires contained questions which were related to postharvest handling methods carried out by farmers, collectors, traders, and exporters, as well as those problems that they encountered. The number of respondents differed at each level in the delivery chain depending on the number of farmers, collectors, traders, and exporters available during the surveys (Israel 1992; Science Buddies 2018).

Samples Collection

The 64 coffee bean samples of 1,000 g/sample were collected randomly from the places where the respondents obtained the coffee beans and packed in a clean plastic polyethylene bag. The samples were then doubly-packed in hermetic bags to minimize changes occurring in the coffee bean samples due to the long transport distance between the sampling location and the laboratory in Bogor, where the samples were analyzed.

The total number of Arabica coffee bean samples in Tana Toraja and North Toraja Regencies, and Makassar Municipality was larger than the number of the respondents. Information on the number of farmers, collectors and traders were obtained from Toraja Coffee Farmers Cooperative (*Koperasi*

Petani Kopi Toraja or KOPTAN PPKT), while that of exporters was obtained from Plant Quarantine Service, Makassar. As many as 27 samples of coffee beans with hull were collected from 24 farmers; 15 samples of coffee beans with hull were from 10 collectors; 13 green coffee bean samples (coffee beans without husk and hull) were from 7 traders; and 9 green coffee bean samples were collected from 4 exporters.

Each sample was mixed homogenously and then divided two times to obtain 4 smaller samples with almost the same weight (± 250 g) using a box divider to obtain working samples for the determination of the MC and quality grade of the coffee beans and fungal population. The samples used to determine the MC and the fungal population were ground using a grinder.

Determination of Moisture Content, Quality Grade of Coffee Beans, and Fungal Population

The hull of each sample was shelled manually before the moisture content, quality grade, and fungal population was measured. The moisture content (MC) of the coffee beans (based on wet basis) was determined using the oven method (SNI 2008). Two replicates were used for each sample. The quality grade of the coffee beans was determined based on the number of defective beans in every 300 g of sample (SNI 2008). The fungi were isolated using the serial dilution method followed by the pour plate method on Dichloran 18% Glycerol Agar (DG18) (Pitt & Hocking 2009). One replicate was used for each sample (1 x 25 g). The fungi were then identified using Pitt and Hocking (2009) method.

The formula to determine moisture content computed on a wet basis:

$$\% MC = W - \frac{(W1 - W2)}{W} \times 100$$

Where W = weight of coffee bean sample before drying
W1 = weight of coffee bean sample and cup after drying
W2 = weight of the cup

The formula to determine the percentage of samples with MC > 13%:

$$\% \text{ samples} = \frac{\text{number of samples with MC} > 13\%}{\text{number of samples collected}} \times 100$$

Statistical Analysis

Data on the moisture content, total fungal population, and populations of *A. niger* and *A. ochraceus* were analyzed using the non-parametric one-way Kruskal-Wallis test, followed by the Mann-Whitney test.

RESULTS AND DISCUSSION

Postharvest Handling of Arabica Coffee at Different Levels of the Delivery Chain

The 45 respondents consisted of 24 farmers, 10 collectors, 7 traders, and 4 exporters (Table 1). Arabica coffee plantations in Tana Toraja and North Toraja Regencies are operated by smallholder plantation owners. The eight coffee-bean-producing districts of Toraja Coffee Farmers Cooperative (*Koperasi Petani Kopi Toraja* or KOPTAN PPKT) are Sesean Suloara, Bangkelekila', Tikala, Kapalapitu, Buntu Pepasan, Awan Rantekarua, Gandasil, and Mengkendek. Four of these eight districts, namely Gandasil, Buntu Pepasan, Kapalapitu, and Sesean Suloara Districts, have larger plantations and higher levels of Arabica coffee bean production. In 2015 the total areas of the coffee plantations in these districts were 538.75, 269.50, 135, and 133.43 has, respectively, while their levels of coffee bean production were 161,208.4 kg; 53,065.6 kg; 26,369.6 kg; and 24,307.32 kg, respectively. The variety of coffee beans cultivated in these regions was Lini S 795. During the survey, the coffee trees ranged from 7 to 31 years old. The coffee trees are intercropped either with white leadtree *(Leucaena leucocephala),* Amboina pine *(Agathis dammara),* Indian coral tree *(Erythrina variegata),* or rubber trees (*Hevea brasilienses*).

Table 1 Number of respondents, sample condition, and number of coffee bean samples collected from various stages of the delivery chain in Tana Toraja and North Toraja Regencies, and Makassar Municipality, South Sulawesi Province, Indonesia

Level of delivery chain	Number of respondents	Sample conditions	Number of samples (at 1,000 g/sample)	
				Total
Farmer	24	HB	27	27
Collector	10	HB	14	15
		GB	1	
Trader	7	HB	2	13
		GB	11	
Exporter	4	GB	9	9
Total	45			64

Notes: HB (hull beans) = coffee beans with hull
GB (green beans) = dried coffee beans without hull and husk

All the farmer respondents (100%) selectively picked only the ripened coffee berries. All the collector and trader respondents collected coffee beans with hull from the farmers, while all the exporter respondents collected green coffee beans (beans without hull and husk) from the traders or collectors.

At farmer level, the coffee berries were collected and stored temporarily in the polypropylene bags for 1 to 3 days (performed by 42% of respondents), or more than 3 days without further processing (performed by 8% of respondents) to accumulate enough quantity for subsequent processing. The farmers used the wet process for the coffee berries. The husks of the berries were shelled, and then the berries were washed with water from the well to ensure good fermentation and to eliminate their mucus. Some farmers shelled the husk by treading on the coffee berries after soaking these in well-water for two days. The coffee beans were then sun-dried for less than seven days on repeatedly-used polypropylene bags or plaited mats. Consequently, the beans got easily infected by fungi. Coffee beans with hulls were then stored in polypropylene bag (performed by 79% of respondents) or stored using the bulk system (performed by 17% of respondents) for less than seven days. The farmers then sold the coffee beans with hulls to the collectors. These farmers usually encountered problems during the drying process, as it takes a longer time to dry the coffee beans, particularly during the rainy season, and this significant delay might have also affected the bean quality. The farmers, though, hoped to get a drying machine from relevant institutions. Another problem encountered by the farmer respondents was the very expensive fertilizer coupled with the low market price of coffee beans.

At the collector level, postharvest handling was conducted faster. The collectors sold the coffee beans with hull to the traders, KOPTAN PPKT, or exporters immediately after they bought these from the farmers. Seventy percent of the collectors also sorted or selected the beans based on grade requirement.

At the trader level or *Koperasi Petani Kopi Toraja*, the coffee beans with hull were re-dried and shelled to produce the green coffee, i.e., coffee beans without husk and hull. The traders sorted the beans based on bean size using a grading machine and on the beans' defective value, manually and then sold these beans to exporters after storage of 7 to 60 days. The traders encountered problems like the lack of roasting equipment and limited capital.

At the trader and exporter levels, inappropriate post-harvesting techniques were carried out during beans storage; sanitation was poor, and some of them did not use any pallet. Before exportation, the exporters stored the green coffee beans (without husk and hull) for six months until two years in a polypropylene bag, jute bag or jute bag doubled with polyethylene bag. Finally, the green beans were fumigated using phosphine before being exported to countries like Australia, Netherlands, United States of America, and Japan.

Table 2 Moisture content and grade of coffee beans at various stages of the delivery chain in Tana Toraja and North Toraja Regencies, and Makassar Municipality, South Sulawesi Province, Indonesia

Level of delivery chain	Number of sample	Moisture content (% wet basis)	Number (%) of samples with MC* > 13%	Quality grade (% sample in each group of quality grade)*
Farmer	27	42.5 ± 12.1 a	26 (96)	1 (11%) 2 (44%) 3 (30%) 4 (7%) 5 (4%) 6 (4%)
Collector	15	42.5 ± 11.3 a	14 (93)	1 (7%) 2 (53%) 3 (40%)
Trader	13	10.9 ± 1.6 b	1 (8)	1 (32%) 2 (23%) 3 (15%) 4 (15%) 5 (15%)
Exporter	9	9.7 ± 0.7 c	0	2 (33%) 4 (45%) 5 (11%) 6 (11%)

Note: *Source: Indonesian National Standard (SNI 2008), Quality grade: 1 = highest; 6 = lowest

Moisture Content and Quality Grade of Coffee Beans

The Indonesian National Standards (SNI) has determined the maximum tolerable limit (MTL) of moisture content (MC) in coffee beans at 13% (SNI 2008). The MC of coffee beans collected from the farmers (42.5 ± 12.1%) and collectors (42.5 ± 11.3%) were higher than the MTL determined by SNI (13%). As high as 96% and 93% of the samples collected from the farmers and collectors had MC exceeding 13% (Table 2). Based on the statistical analysis, different levels of the delivery chain made a significant difference in the MC of the coffee beans. MC of the beans collected from the farmers was not significantly different from that of the collectors. However, MC of the beans collected from farmers and collectors were significantly higher than those of the traders and exporters.

The MC of coffee beans collected from the traders (10.9 ± 1.6%) and exporters (9.7 ± 0.7%) were generally lower than the maximum tolerable limit determined by SNI (13%). Nevertheless, 8% of 13 coffee bean samples collected from traders had MC exceeding 13%. The traders and exporters re-dried and re-sorted the coffee beans from farmers and collectors to meet the required standard of quality. Based on the total defective value, the quality grade of coffee beans from the farmers was the most diverse (grades 1 to 6) compared to those from the collectors (grades 1 to 3), traders (grades 1 to 5), and exporters (grades 2 to 6) (Table 2).

Fungal Diversity and Population in the Coffee Beans

Based on their visual observations, the respondents claimed that no fungal problems were observed in their coffee beans. However, based on the scientific results of fungal isolation, all coffee bean samples were found to be infected by fungi.

Eleven fungal species were isolated from the coffee beans collected from farmers (Table 3). The most common fungal species isolated from the 27 coffee bean samples were *Penicillium citrinum* (85%), *Fusarium solani* (26%), *Aspergillus ochraceus* (19%), and *Endomyces fibuliger* (11%). Eleven fungal species were also isolated from the 15 coffee bean samples of the collectors and the most common species were *P. citrinum* (100%), *Cladosporium cladosporioides* (27%), *Endomyces fibuliger* (20%), and *F. verticillioides* (20%). Ten fungal species were isolated from the 13 coffee bean samples of the traders and the most common were *Penicillium citrinum*

(85%), *A. flavus* (54%), *Aspergillus ochraceus* (46%), *A. niger* (46%), *A. tamarii* (38%), and *Eurotium chevalieri* (38%). Nine fungal species were isolated from the 9 coffee bean samples of the exporters and the most common were *Aspergillus niger* (78%), *A. tamarii* (67%), *P. citrinum* (56%), *A. ochraceus* (56%), and *A. flavus* (44%). From among the species found, *A. niger* and *A. ochraceus* are known to produce OTA.

In Central and South Vietnam, *Aspergillus carbonarius, A. niger,* and yellow Aspergilli (*A. ochraceus* and other species which include the *Circumdati* group) were isolated from 65 samples of Robusta coffee beans and from 11 samples of Arabica coffee beans (Leong *et al.* 2007). As much as 89% of Robusta coffee bean samples were infected by *A. niger*, while 12% and 14% of the samples were infected by yellow Aspergilli and *A. carbonarius*, respectively.

In South Cordoba Province, Argentina, 50 samples of Colombian coffee beans (25 green and 25 roasted) were obtained from a processor (Magnoli *et al.* 2008) and the green samples were found to be infected predominantly with *A. niger* agregate, while that found in roasted coffee was with *A. flavus*, followed by *A. niger* aggregate. In the north Chiang Mai Province, Thailand, 32 samples of dried Arabica coffee beans collected from two growing sites were 78% infected with *Aspergillus* of section *Circumdati* group with *A. westedijkiae* and *A. melleus* as the predominant species (Noonim *et al.* 2008). *Aspergillus* spp. of section *Nigri* was found in 75% of the samples, whereas *A. ochraceus* was not found.

From the South of Minas Gerais, Brazil, 480 filamentous fungi of the genera *Aspergillus* of the *Circumdati* and *Nigri* sections were isolated from 30 samples of Arabica coffee beans collected from the cultivation of 10 organic and 20 conventional samples (de Fatima *et al.* 2013). The ochratoxigenic species identified were *A. auricoumus*, *A. ochraceus*, *A. ostianus*, *A. niger* and an agregate of *A. niger*. Black aspergilli (*A. aculeatus*, *A. carbonarius*, *A. niger* and *A. tubingensis*) were also found in 12 samples of dried coffee beans collected from farmers of Kulon Progo District, Yogyakarta (Nugroho *et al.* 2013). The OTA producing strains were identified as *A. carbonarius* and *A. niger*, while *A. tubingensis* and *A. aculeatus* were found as the non-OTA producing strains. The two important fungal species with the OTA-producing potential that were found in Cameroonian coffee beans, *A. carbonarius* and *A. niger* (Nganou *et al.* 2014), were also predominant in Arabica and Robusta beans.

Generally, the species of OTA producing fungi found in this research were similar to those reported by other researchers.

Table 3 Fungal diversity and population in coffee beans collected at various stages of the delivery chain in Tana Toraja and North Toraja Regencies, and Makassar Municipality, South Sulawesi Province, Indonesia

Fungi	Farmer (27 samples)		Collector (15 samples)		Trader (13 samples)		Exporter (9 samples)	
	Number (%) of samples infected by fungi	Range (mean) of fungal population (cfu/g wet basis)	Number (%) of samples infected by fungi	Range (mean) of fungal population (cfu/g wet basis)	Number (%) of samples infected by fungi	Range (mean) of fungal population (cfu/g wet basis)	Number (%) of samples infected by fungi	Range (mean) of fungal population (cfu/g wet basis)
Aspergillus candidus	1 (4)	1.1 x 10^2 (1.1 x 10^2)	2 (13)	6.7 x 10 - 1.3 x 10^2 (1 x 10^2)	-	-	-	-
A. flavus	3 (11)	2.3 x 10 - 1.3 x 10^2 (7.4 x 10)	1 (7)	3 x 10 (3 x 10)	7 (54)	0.3 x 10 - 7.7 x 10^2 (2.4 x 10^2)	4 (44)	0.7 x 10 - 1.7 x 10^2 (5 x 10)
A. ochraceus	5 (19)	0.7 x 10 - 5 x 10^2 (1.4 x 10^2)	1 (7)	2.3 x 10^2 (2.3 x 10^2)	6 (46)	0.3 x 10 - 2.7 x 10^3 (7.4 x 10^2)	4 (44)	0.3 x 10 - 7 x 10 (2 x 10)
A. niger	1 (4)	6.3 x 10 (6.3 x 10)	-	-	6 (46)	0.3 x 10 - 1.3 x 10^3 (4.8 x 10^2)	7 (78)	0.3 x 10 - 8.3 x 10^2 (3.1 x 10^2)
A. sydowii	-	-	-	-	1 (8)	1.7 x 10 (1.7 x 10)	1 (11)	2 x 10 (2 x 10)
A. tamarii	-	-	-	-	5 (38)	0.3 x 10 - 2.3 x 10^2 (7.1 x 10)	6 (67)	0.3 x 10 - 1.3 x 10^2 (5.1 x 10)
A. versicolor	-	-	1 (7)	3.7 x 10^3 (3.7 x 10^3)	-	-	2 (22)	0.7 x 10 - 6 x 10 (3.4 x 10)
A. wentii	2 (7)	(0.3 - 1.7) x 10 (1 x 10)	1 (7)	1 x 10^2 (1 x 10^2)	-	-	-	-
Cladosporium cladosporioides	-	-	4 (27)	2 x 10^2 - 2.3 x 10^3 (1.4 x 10^3)	-	-	-	-
Endomyces fibuliger	3 (11)	2.7 x 10^2 - 1 x 10^4 (5.1 x 10^3)	3 (20)	1.7 x 10^2 - 1.3 x 10^4 (5.3 x 10^3)	-	-	-	-
Eurotium chevalieri	3 (11)	1 x 10 - 1.1 x 10^3 (4 x 10^2)	-	-	5 (38)	0.7 x 10 - 4.7 x 10^2 (1.2 x 10^2)	3 (33)	6.3 x 10 - 1 x 10^2 (8.2 x 10)
E. rubrum	1 (4)	4.3 x 10^2 (4.3 x 10^2)	2 (13)	3.7 x 10^2 - 6.3 x 10^3 (3.4 x 10^3)	3 (23)	3.3 x 10 - 1 x 10^2 (6.7 x 10)	-	-

Fusarium solani	7 (26)	1.7 x 10^3 - 8 x 10^4 (1.9 x 10^4)	2 (13)	7.7 x 10^3 - 1.3 x 10^4 (1.1 x 10^4)	1 (8)	4 x 10^3 (4 x 10^3)	-	-
F. verticillioides	4 (15)	5.3 x 10 - 4 x 10^3 (1.2 x 10^3)	3 (20)	1.3 x 10^2 - 3.7 x 10^3 (1.5 x 10^3)	3 (23)	1 x 10^2 - 3 x 10^3 (1.2 x 10^3)	2 (22)	0.7 x 10 - 4 x 10 (2.4 x 10)
Penicillium citrinum	23 (85)	0.3 x 10 - 4.3 x 10^4 (6.3 x 10^3)	15 (100)	1 x 10 - 6 x 10^4 (1.1 x 10^4)	11 (85)	0.3 x 10 - 4.6 x 10^4 (1.2 x 10^4)	5 (56)	0.7 x 10 - 3.3 x 10^2 (1.5 x 10^2)

Table 4 The effect of different stages of the delivery chain of coffee beans on the total fungal population and populations of *Aspergillus niger* and *A. ochraceus*

Level of delivery chain	Total fungal population (cfu/g wet basis)	Population of *A. niger* (cfu/g wet basis)	Population of *A. ochraceus* (cfu/g wet basis)
Farmer	3.0 x 10^4 ± 7.2 x 10^4 a*	6.3 x 10 a*	1.4 x 10^2 ± 1.9 x 10^2 a
Collector	1.5 x 10^4 ± 2.1 x 10^4 a	0 a	2.3 x 10^2 a
Trader	1.3 x 10^4 ± 2.0 x 10^4 a	4.8 x 10^2 ± 5.7 x 10^2 b	7.4 x 10^2 ± 1.5 x 10^3 a
Exporter	4.9 x 10^2 ± 3.9 x 10^2 a	3.1 x 10^2 ± 3.4 x 10^2 b	2 x 10 ± 3.4 x 10 a

Note: *a – b = means of the same letter in a column are not significantly different at 95% level of significance based on Mann Whitney test

The population of *A. ochraceus* in the coffee beans collected from exporters (2 x 10 cfu/g) was significantly the lowest, compared to those collected from farmers (1.4 x 10^2 cfu/g), collectors (2.3 x 10^2 cfu/g), and traders (7.4 x 10^2 cfu/g) (Table 3). Remarkably, *A. niger* was not found in coffee beans from the collectors. Its population in the coffee beans from the farmers (6.3 x 10 cfu/g) was the lowest, compared to those from exporters (3.1 x 10^2 cfu/g) and traders (4.8 x 10^2 cfu/g). The mean total fungal populations in coffee beans collected from farmers, collectors, traders and exporters were 3.0 x 10^4, 1.5 x 10^4, 1.3 x 10^4 and 4.9 x 10^2 cfu/g, respectively. BPOM (2016) has set the limit of fungal population for mould and yeast in powder and instant coffees at 10^4 and 10^3 cfu/g, respectively, but no known limit is set for fungal population in coffee beans.

The high MC of coffee beans from the farmers and collectors resulted in the high fungal diversity and population in the samples. However, the traders' and exporters' re-drying and re-sorting of the coffee beans from the farmers and collectors, resulted in improving the quality of the coffee beans that the MC and fungal population were relatively low in the samples. The number of defective beans in every sample has also affected fungal diversity and population. The high fungal diversity was also probably due to the kind of substrate (Toraja Arabica coffee beans) and other environmental factors affecting fungal infection in stored foodstuff, such as water quality, hydrogen ion concentration, both the processing and storage temperature, gas tension of oxygen and carbon dioxide, consistency, nutrient status, specific solute effects, and preservatives (Pitt & Hocking 2009). Moreover, fungal diversity found in cereal grain is influenced by abiotic factors such as the ambient temperature and relative humidity, especially at a microclimate level (Magan *et al.* 2010). Thus, the fungi colonizing these ecological niches will interact with each other as they compete in utilizing the available nutrients.

Based on statistical analysis, the different delivery chains significantly affected the population of *A. niger* but not the total fungal population nor that of *A. ochraceus* (Table 4). The populations of *A. niger* in coffee bean samples collected from traders (4.8 x 10^2 cfu/g) and exporters were significantly higher (3.1 x 10^2 cfu/g) than those of samples from farmers (6.3 x 10 cfu/g) and collectors (0 cfu/g).

CONCLUSION

Generally, the coffee bean samples collected from various stages of the delivery chain were infected by fungi. The percentage of coffee beans infected by the OTA producing fungi (*A. niger* and *A. ochraceus*) were relatively high at trader and exporter levels. The populations of some fungal species exceeded the limit determined by BPOM (2016), while the populations of *A. niger* and *A. ochraceus* were lower than the limit. Fungal diversity and population in the coffee beans collected from various stages of the delivery chain were influenced by moisture contents and defective beans, interaction among fungi, and duration of storage. Moreover, the postharvest handling

methods of farmers, collectors, traders, and exporters of coffee beans in Tana Toraja and North Toraja Regencies, and Makassar Municipality, South Sulawesi Province, must be improved to prevent the possibility of OTA contamination. Lastly, even though the populations of OTA-producing fungi were found to be lower than the limit determined by SNI, the presence of OTA-producing fungi might indicate OTA contamination of Arabica coffee beans.

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