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Effect of Temperature and Relative Humidity during Transportation on Green Coffee Bean Moisture Content and Ochratoxin A Production

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ABSTRACT

Changes in temperature, relative humidity, and moisture content of green coffee beans were monitored during transportation of coffee from Brazil to Italy. Six containers (three conventional and three prototype) were stowed in three different places (hold, first floor, and deck) on the ship. Each prototype was located next to a conventional container. The moisture content of the coffee in the container located on the first floor was less affected by environmental variations (0.7%) than that in the hold and on the deck. Coffee located in the hold showed the highest variation in moisture content (3%); in addition, the container showed visible condensation. Coffee transported on the deck showed an intermediary variation in moisture (2%), and there was no visible condensation. The variation in coffee moisture content of the prototype containers was similar to that of the conventional ones, especially in the top layers of coffee bags (2 to 3%), while the increase in water activity was 0.70. This suggests that diffusion of moisture occurs very slowly inside the cargo and that there are thus sufficient time and conditions for fungal growth. The regions of the container near the wall and ceiling are susceptible to condensation since they are close to the headspace with its high relative humidity. Ochratoxin A production occurred in coffee located at the top of the container on the deck and in the wet bags from the hold (those found to be wet on opening the containers at the final destination).

In coffee-producing countries such as Brazil, green coffee bean exportation to Europe, North America, or Asia usually occurs from September to January, which is summer in the tropics and winter in the northern hemisphere. On maritime routes between regions of tropical climate, such as Brazil in summer, and those of temperate climate, such as the northern hemisphere, there are drastic temperature oscillations during transportation, causing moisture gain or loss inside dynamic, nonhermetic systems such as the containers used for coffee transportation *(15, 20)*.

Changes in temperature during grain transportation can result in moisture transfer. Differences of 2 to 3°C favor migration, while differences of 5 to 10°C between one region and another favor faster moisture transfer *(9)*. The warmer region tends to lose water, which is absorbed by the colder region *(17)*. Grain intrinsic factors, such as moisture content and water activity, as well as the extrinsic factors, such as temperature and relative humidity, are useful parameters to evaluate certain inherent grain quality characteristics *(18)*.

Coffee-producing and coffee-exporting countries aim to obtain good-quality, safe products and maintain this tendency throughout the productive chain. However, some factors are out of the control of both producers and exporters. These factors can be climatic or a result of logistic structures, possibly causing undesirable changes in the grain characteristics, permitting fungal growth and subsequent mycotoxin production *(11)*.

Ochratoxin A (OA) has been found in samples of raw, roasted, and soluble coffee from several countries *(8, 10, 14, 16, 21, 22, 24)*. The presence of OA in coffee indicates that fungi capable of producing this toxin have infected the coffee beans at some stage of the coffee production. Fungal ochratoxigenic species that have been found and isolated from various soils and coffee farms are *Aspergillus ochraceus, Aspergillus carbonarius,* and *Aspergillus niger (6, 13, 21, 23)*.

Coffee has different moisture contents at the harvesting stage, varying from 50 to 70% in ripe cherries, from 35 to 50% in coffee raisins (almost dried) on the plant, and from 16 to 30% in cherries that have completely dried on the plant *(7)*. At the end of the drying process, the moisture content must be at or below 12% to prevent fermentation and mold growth *(3)*. It has been shown in previous studies that the presence of OA in coffee is normally a result of badly controlled harvesting procedures and precarious drying and inadequate storage conditions, allowing the proliferation of toxigenic fungi *(1, 21)*. The effect of rewetting coffee after it has been dried is little known, although there is the possibility that this is also a cause of ochratoxin production, especially during storage and transport. Palacios-

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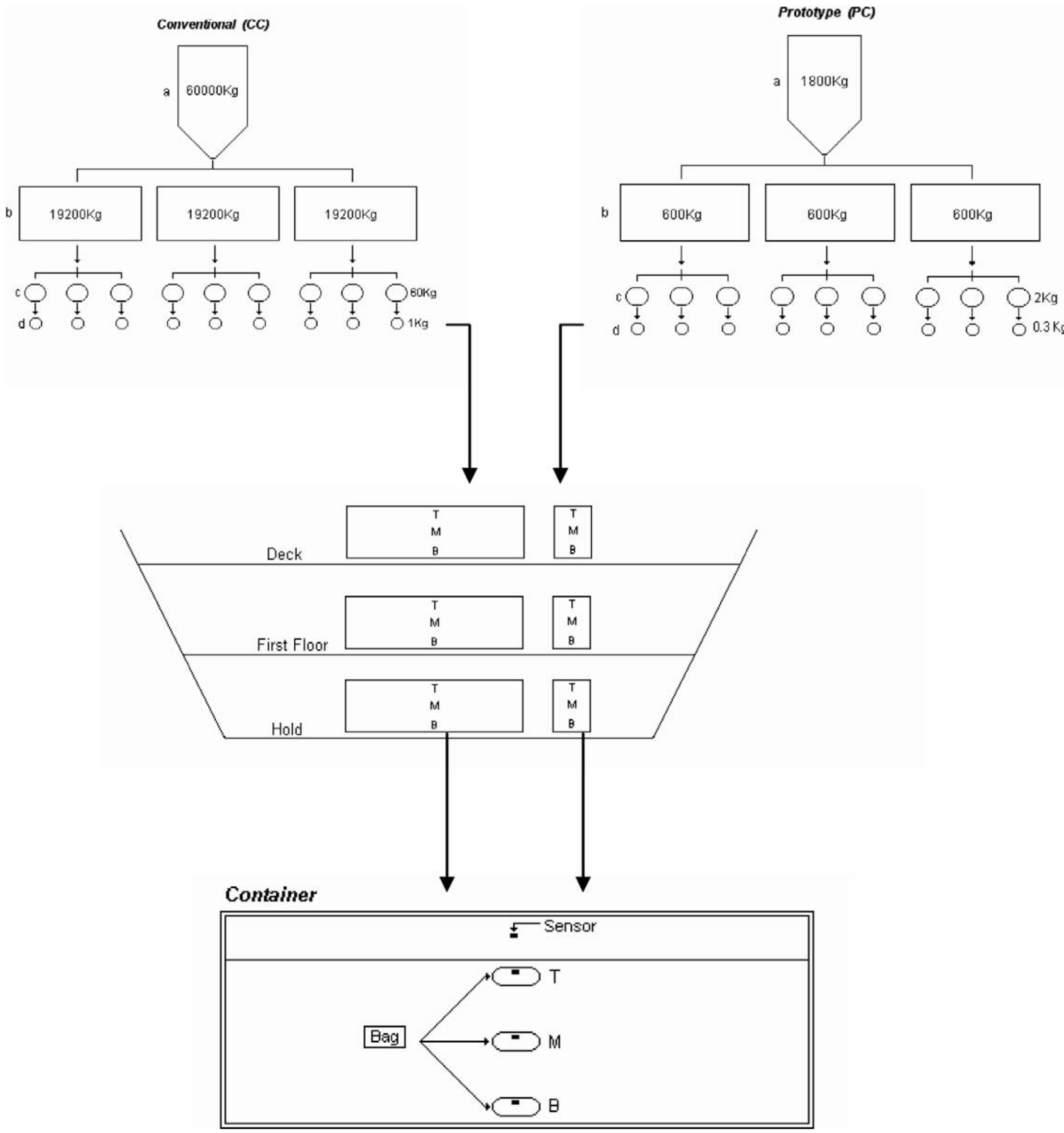

FIGURE 1. *Experimental design. Sampling and placing of conventional and prototype containers in the vessel. Conventional containers (CC): (a) silo of 60,000-kg capacity; (b) three conventional containers with 19,200 kg of green coffee beans; (c) 60-kg bag in which the sensors were placed; and (d) samples of 1 kg for analyses. Prototype containers (PC): (a) silo of 1,800-kg capacity; (b) three prototype containers with 600 kg of green coffee beans; (c) 2-kg bag in which the sensors were placed; and (d) sample of 0.3 kg for analyses. Location in the vessel: deck, first floor, and hold. Container region: top (T), middle (M), and bottom (B).*

Cabrera et al. *(11)* showed that OA can be produced in coffee after it has been dried if the coffee is stored in an environment with an equilibrium relative humidity higher than 87%. In this study *(11),* green coffee beans inoculated with *A. ochraceus* were stored at alternating temperatures of 14 and 25°C and equilibrium relative humidities of 80, 87, and 95%. After 39 days, OA production in the green coffee beans was 794 and 2,307 μg/kg at 87 and 95% equilibrium relative humidity, respectively.

Little research has been carried out on green coffee bean transportation. In the present study, prototype containers were validated in order to use them in later pilot studies, simulating long-distance voyages and thus avoiding the necessity of gathering data from conventional containers, which would be complicated and expensive. Therefore, the objectives of the present study were as follows: (i) to supply data on relative humidity, temperature, and green coffee bean moisture content in different locations inside the vessel (hold, first floor, and deck), as well as in different regions inside the container (top, middle, bottom, and headspace); (ii) to compare and validate the data obtained from real and prototype containers; and (iii) to evaluate OA production in green coffee beans during transportation.

MATERIALS AND METHODS

Experimental design. Figure 1 shows the experimental design of the present study. Arabica Brazilian green coffee beans were used in this trial.

Sampling. For conventional containers, the following steps were carried out. (i) From a silo of approximately 60,000-kg capacity, coffee beans were homogenized. (ii) Coffee beans were distributed in 320 bags of 60 kg per container, for a total of 19,200 kg. (iii) Three conventional containers were used in this study; for each container, three bags were selected randomly and identified in which the sensors were placed. (iv) From each bag, a sample of 1 kg was taken for analysis of water activity, moisture content, and OA. This first sampling corresponded to the initial determination of the parameters monitored. From the same identified bags, samples of 1 kg were collected in Trieste (Italy) for the final determinations. Trieste was the final destination of the conventional containers.

For the prototypes, the following steps were carried out. (i) Thirty bags of 60 kg of coffee were homogenized in a smaller silo. (ii) Coffee beans were transferred into 300 small bags of 2 kg, each prototype having a total of 600 kg. (iii) From each prototype, three small bags were chosen randomly and identified, and the sensors were placed the same as in the conventional containers. (iv) From each bag, a sample of 0.3 kg was collected for analysis of water activity, moisture content, and OA. During the sea voyage, two samplings were performed. The prototype had nine holes sealed with screws, which allowed samples to be taken with a special bag sample collector. Samples were taken from the bottom, middle, and top of the containers for moisture content measurement. In the final sampling at Livorno (Italy), 1 kg from each region was collected for moisture content, water activity, and OA analyses. Livorno was the final destination for prototype containers because they had to return to Brazil in the same vessel.

Conventional and prototype containers. Three conventional containers measuring 5.88 by 2.32 by 2.19 m and three prototype containers measuring 1.86 by 0.73 by 0.73 m were used. To validate the prototype data compared with the conventional container, polystyrene was used to line three lateral walls of the prototype. The top and one wall were not lined with polystyrene in order to simulate one segment of a real container. The prototypes were placed in a vertical position close to the end of the conventional ones, as shown in Figure 1.

Moisture content analysis. The moisture content was determined with the electric capacitance equipment (model 600, Gehaka Ltd., São Paulo, Brazil) previously calibrated according to the International Organization for Standardization 1447 *(5)* oven method at 130 ± 2°C for 6 and 4 h. The Gehaka 600 measured the moisture content in situ during the voyage. A temperature correction was also made for the final results.

Water activity determination. The water activity was measured with an Aqualab model 3TE (Decagon, Pullman, Wash.) with three repetitions. The water activity was measured at the beginning and end of the voyage.

Analysis of OA in the coffee. The coffee samples were analyzed for OA according to Vargas et al. *(25)*. The samples were extracted with a solution of methanol:3% sodium bicarbonate (50:50). The extracts were filtered and diluted with phosphate-buffered saline and applied to an immunoaffinity column (Vicam, Watertown, Mass.) containing a monoclonal antibody specific for OA. After washing, the OA was eluted with high-performance liquid chromatography (HPLC)–grade methanol and quantified by reverse-phase HPLC with a fluorescence detector. The mobile phase used was methanol:acetronitrile:water:acetic acid (35:35:29:10). The flow rate was 0.8 ml/min. The equipment used was a Shimadzu LC-10VP system (Shimadzu Corporation, Tokyo, Japan) set at 330-nm excitation and 470-nm emission. The HPLC was equipped with an ODS Hypersil (5 μm, 25 by 4.6 mm) precolumn and Supelcosil LC-18 (5 μm, 250 by 4.6 mm) column (Supelco, Bellefonte, Pa.). The OA detection method in green coffee beans was validated at the Food Technology Institute (Campinas, Brazil). Samples with three repetitions were spiked with OA standard (Sigma, St. Louis, Mo.) at three levels (4.8, 8.0, and 80.0 μg/kg). The OA recovery percentages obtained were 86.5, 78, and 81%. The detection and quantification limits of the method were 0.1 and 0.3 μg/kg, respectively.

Extrinsic factors monitored during the voyage. Temperature and relative humidity were monitored with Onset (HO8-032-08, Onset Computer, Bourne, Mass.) calibrated sensors. Four sensors were placed inside the conventional containers at the bottom, middle, top, and headspace. In all, 12 sensors were used for the conventional containers. The sensors were protected inside a stainless steel cage. In the prototype, the same location criteria were used.

Coffee transportation trajectory from Leme (Brazil) to Santos (Brazil). The coffee was first taken from the farms to a storage place in Leme, where it was classified and selected by the importer. In Leme, the selected coffee beans were repacked in the 60-kg bags. The sensors were placed in the bags and minibags at this time. The coffee bags remained in the storage place for 3 days until the road transportation authorization was obtained. They were then loaded onto a truck and covered by a canvas top. The total road trajectory from Leme to Santos was 274 km, and the journey took approximately 8 h.

Container filling in Santos. The coffee bags were put into the container in Santos. The identified bags containing the sensors were placed at the center of the conventional containers. The coffee bags were covered with kraft paper to protect them against moisture. The real containers were closed, and they were opened only at the final destination in Trieste. In a similar way, the prototypes were also filled in Santos, and the sensors were put in place. The containers were stored at a terminal called Tecondi in Santos for 12 days. This was the time needed to get the authorization for maritime transportation and for the arrival of the vessel.

Coffee embarkation onto the vessel. The conventional and prototype containers were placed on the vessel in three positions: deck, first floor, and hold. The deck was located at the top, where the containers are drastically affected by climatic changes. The first floor of the vessel is above the hold at sea level. The hold of the vessel is 5 m below sea level, where air circulation is greatly reduced compared with the first floor.

Maritime transportation. The sea voyage took 14 days.

Arrival in Italy. In Livorno, the sensors from the three prototype containers were removed, and samples for OA, moisture content, and water activity were collected. The prototype containers returned to Brazil on the same ship, because of the impossibility of getting permission to continue the trip to Trieste inland with the conventional containers.

Railway transportation from Livorno to Trieste. The three conventional containers were transported by train from Livorno to Trieste. This took 10 days, including the time that the containers were stored in Livorno Port.

Coffee unloading in Trieste. In Trieste, the conventional containers were opened, and the coffee bags were unloaded. The sensors and samples were taken from the conventional containers for later analyses. It was verified whether the container ceiling showed signs of condensation. Some bags were wet and were separated from the others. Samples from these wet bags were also collected.

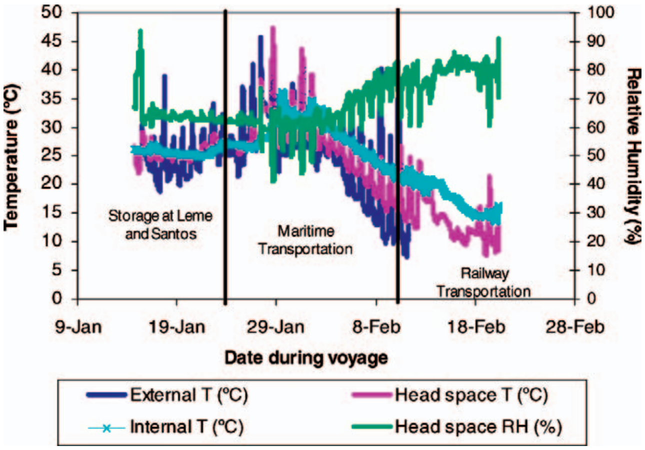

FIGURE 2. *Changes in temperature and relative humidity during transportation from Leme (Brazil) to Trieste (Italy).*

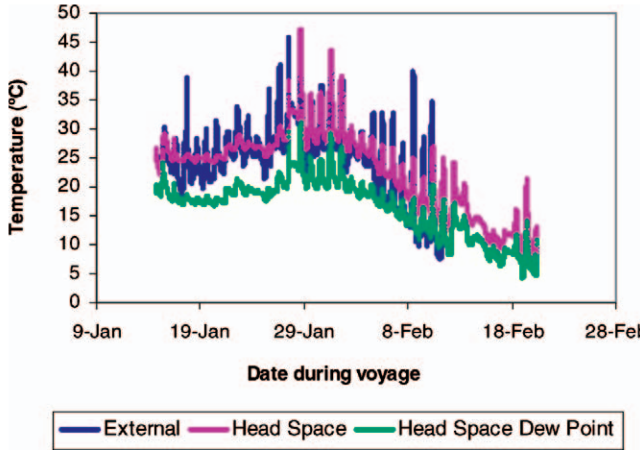

FIGURE 3. *Changes in temperature during coffee transportation: (a) external region, (b) headspace, and (c) headspace dew point temperature.*

Statistical analysis. The experimental design was completely randomized. All results were analyzed by the Tukey test at a level of 5% probability.

RESULTS AND DISCUSSION

Figure 2 shows the temperature and relative humidity changes during road transport from Leme to Santos, storage in the terminal at Santos, the sea voyage, and rail transportation in Italy. It can be observed that the temperature started to decrease at the end of the sea voyage. During rail transportation in Italy, the temperature decreased drastically, and the relative humidity increased proportionally.

The moisture content and water activity of the coffee beans monitored during transportation from the beginning (Leme, Brazil) to the end (Trieste, Italy) of the journey are shown in Table 1. All coffee trade is carried out on a wet weight basis, while in the scientific world, the dry weight basis is more often used. For this reason, both measurements are presented for greater clarification. The locations of the containers in the vessel corresponded to the deck, first floor, and hold, and the samples from the three regions of the container corresponded to the bottom, middle, and top.

In general, there was a significant increase in moisture content at the end of the voyage at the top of the three containers, as shown in Table 1. This may have been due to (i) the relative humidity being increased inside the container (at the end of the maritime transportation) as a consequence of the decrease in external temperature, as shown in Figure 2; or (ii) the external temperature being lower than the dew point temperature, causing condensation on the container plate (metal sheet), which in turn caused water formation on the bean surface, as shown in Figure 3. This may have been the main cause of the increase in bean moisture content at the end of the voyage.

In the other areas of the containers (middle and bottom), no increases in moisture content were observed. This

TABLE 1. *Initial and final moisture contents on wet and dry weight bases and water activity (a_w) of coffee beans during transportation from Leme to Trieste (in conventional containers)*

Location in the vessel	Container region	a_w (initial)	a_w (final)	Minimum SD[a]	Wet wt/dry wt, % (initial)	Wet wt/dry wt, % (final)	Minimum SD[a]
Deck	Bottom	0.59 ± 0.00 A[b]	0.59 ± 0.00 A	0.00	10.87/12.20 ± 0.00 A	10.83/12.14 ± 0.10 A	0.17
	Middle	0.59 ± 0.00 A	0.58 ± 0.00 A	0.00	10.75/12.05 ± 0.20 B	12.10/13.77 ± 0.13 A	0.39
	Top	0.59 ± 0.00 A	0.64 ± 0.00 A	0.00	10.92/12.26 ± 0.27 B	12.38/14.13 ± 0.10 A	0.47
	Wet bags[c]	0.59 ± 0.00 A	0.60 ± 0.00 A	0.00	10.87/12.19 ± 0.02 B	11.92/13.53 ± 0.13 A	0.21
First floor	Bottom	0.54 ± 0.02 A	0.53 ± 0.00 A	0.03	9/97/11.08 ± 0.10 A	10.07/11.20 ± 0.27 A	0.45
	Middle	0.58 ± 0.00 A	0.54 ± 0.00 B	0.00	10.12/11.26 ± 0.10 B	10.97/12.32 ± 0.27 A	0.47
	Top	0.58 ± 0.00 A	0.60 ± 0.00 A	0.00	10.97/12.32 ± 0.10 B	11.63/13.16 ± 0.10 A	0.24
	Wet bags[c]	0.56 ± 0.03 A	0.57 ± 0.00 A	0.05	10.69/11.97 ± 0.72 A	10.68/11.96 ± 0.10 A	1.16
Hold	Bottom	0.56 ± 0.01 A	0.57 ± 0.00 A	0.01	11.02/12.38 ± 0.18 A	10.83/12.14 ± 0.10 A	0.33
	Middle	0.61 ± 0.00 A	0.58 ± 0.00 A	0.00	11.30/12.74 ± 0.18 A	10.83/12.14 ± 0.10 B	0.33
	Top	0.61 ± 0.01 B	0.63 ± 0.00 A	0.01	10.82/12.13 ± 0.60 B	12.00/13.60 ± 0.18 A	0.01
	Wet bags[c]	0.59 ± 0.03 B	0.70 ± 0.00 A	0.05	11.02/12.38 ± 0.18 B	14.27/16.64 ± 0.33 A	0.05

[a] All results were analyzed by the Tukey test at an error level of 5% probability.
[b] Samples (average ± standard deviation) followed by the same letter do not differ at the 5% level.
[c] Bags that were wet when the containers were opened in Italy yet were not wet initially.

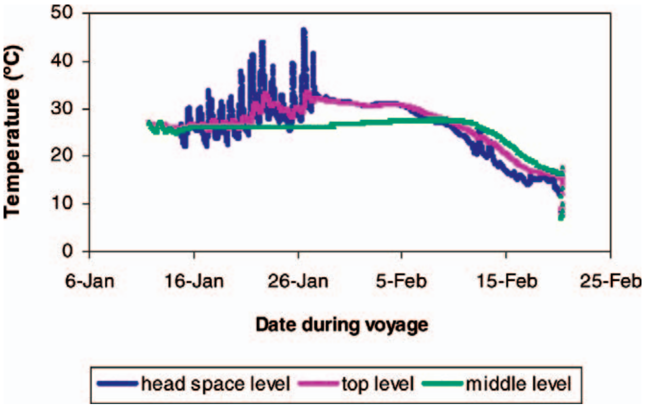

FIGURE 4. *Changes in temperature inside the conventional container: (a) headspace, (b) top level, and (c) middle level.*

was possibly because of the diffusion of moisture content, which is slow and proportional to temperature changes. When the temperature decreases, the relative humidity increases, as does the moisture content of the beans. Figure 4 shows the difference in temperatures registered by the sensors, which were located in the headspace, top, and middle of the coffee cargo in each conventional container. Thus, the tendency for humidity diffusion to occur from warmer regions to colder regions is evident. The temperature in the headspace decreased before it did at the top and in the middle, as clearly seen in the bean moisture content changes (Table 1).

Moisture content and water activity data of the three prototypes located next to the conventional containers, determined at the start (Leme), during the middle, and at the end of the journey (Livorno), are shown in Table 2. The prototypes finished their outward journey at Livorno and returned to Brazil in the same vessel; they did not accompany the conventional containers to Trieste. In general, the moisture content increased significantly on the three decks during the voyage, especially in coffee bean samples taken from the top. Since the prototypes were much smaller than the conventional containers, the convection cycle of vapor pressure was faster, and the distribution of moisture content in the coffee mass was more homogeneous.

While unloading the coffee bags from the conventional containers in Trieste, some from each of the three containers showed signs of wetness. These bags were at the top and closest to the lateral walls of the containers and were wet because of condensation dripping from the container ceiling. These bags were separated from the others. The coffee beans inside these bags had a whitish color, and some were lumped together. Coffee beans from these bags showed high moisture content and water activity (Table 1) and high OA content (Table 3). Up to now, there are only a few countries that have set national limits on green coffee, such as Italy, 8 μg/kg; Finland, 10 μg/kg; and Greece, 20 μg/kg *(2)*. Some coffee companies in Europe have also set their own limits. Considering the national regulation, Italy and Finland would reject the coffee from wet bags, which had 13.13 μg/kg (Table 3).

When the conventional containers were opened in Tri-

TABLE 2. *Moisture contents on wet and dry weight bases and water activity (a_w) of coffee beans during transportation from Leme to Livorno (prototype containers)*

Location in the vessel	Container region	a_w (initial)	a_w (final)	Minimum SD[a]	Wet wt/dry wt, % (initial)	Wet wt/dry wt, % 29 Jan.	Wet wt/dry wt, % 3 Feb.	Wet wt/dry wt, % (final)	Minimum SD[a]
Deck	Bottom	0.57 ± 0.02 B[b]	0.60 ± 0.09 A	0.017	11.95/13.57 ± 0.07 B	11.58/13.10 ± 0.07 C	—	12.64/14.47 ± 0.10 A	0.20
	Middle	0.56 ± 0.18 A	0.59 ± 0.02 A	0.028	11.97/13.60 ± 0.01 B	11.58/13.10 ± 0.07 C	—	12.34/14.08 ± 0.10 A	0.18
	Top	0.57 ± 0.13 B	0.63 ± 0.01 A	0.020	11.98/13.61 ± 0.03 B	11.72/13.28 ± 0.07 C	—	13.73/15.92 ± 0.11 A	0.19
First floor	Bottom	0.57 ± 0.03 B	0.58 ± 0.02 A	0.005	11.98/13.61 ± 0.02 A	11.72/13.28 ± 0.07 B	11.24/12.66 ± 0.00 B	12.10/13.77 ± 0.10 A	0.19
	Middle	0.56 ± 0.12 B	0.59 ± 0.02 A	0.020	11.95/13.57 ± 0.02 A	11.24/12.66 ± 0.14 B	11.51/13.01 ± 0.14 B	12.10/13.77 ± 0.10 A	0.22
	Top	0.57 ± 0.02 B	0.59 ± 0.02 A	0.004	11.96/13.58 ± 0.02 BA	11.51/13.01 ± 0.28 B	11.72/13.28 ± 0.07 B	12.40/14.16 ± 0.18 A	0.47
Hold	Bottom	0.57 ± 0.03 A	0.57 ± 0.02 A	0.005	11.96/13.58 ± 0.01 BA	10.96/12.31 ± 0.14 B	11.24/12.66 ± 0.14 B	12.16/13.84 ± 0.10 A	0.25
	Middle	0.57 ± 0.01 B	0.58 ± 0.02 A	0.003	11.95/13.57 ± 0.01 A	10.61/11.87 ± 0.07 D	11.24/12.66 ± 0.14 C	12.34/14.08 ± 0.21 B	0.34
	Top	0.57 ± 0.04 B	0.60 ± 0.06 A	0.012	11.95/13.57 ± 0.02 B	10.89/12.22 ± 0.07 D	11.72/13.28 ± 0.07 C	12.94/14.86 ± 0.00 A	0.13

[a] All results were analyzed by the Tukey test at an error level of 5% probability.
[b] Samples (average ± standard deviation) followed by the same letter do not differ at the 5% level.

TABLE 3. *Initial and final ochratoxin A (OA) concentrations in coffee from the conventional containers*

Location in the vessel	Container region	OA concn (μg/kg)	
		Initial	Final
Deck	Bottom	ND[a]	0.33
	Middle	ND	0.1
	Top	ND	7.91
	Wet bags[b]	ND	ND
First floor	Bottom	1.65	0.16
	Middle	0.19	<0.1
	Top	1.03	0.74
	Wet bags	ND	ND
Hold	Bottom	1.54	0.17
	Middle	0.30	0.26
	Top	ND	0.28
	Wet bags	ND	13.13

[a] Not detected (limit of detection, 0.1 μg/kg).
[b] Bags that were wet when the containers were opened in Italy yet were not wet initially.

TABLE 4. *Initial and final ochratoxin A (OA) concentrations in coffee beans transported in prototype containers*

Location in the vessel	Container region	OA concn (μg/kg)[a]	
		Initial	Final
Deck	Bottom		2.85
	Middle	0.20	1.01
	Top		2.38
First floor	Bottom		1.22
	Middle	0.20	2.06
	Top		0.45
Hold	Bottom		0.20
	Middle	0.20	1.29
	Top		0.66

[a] Limit of detection, 0.1 μg/kg.

este, those located in the hold and on the first floor showed condensation on the ceiling. This condensation was not observed in the container located on the deck, possibly because the high humidity in the headspace of the containers was lost to the environment as vapor, and part was transferred to the cargo. The environmental conditions on the deck might have contributed to the drying and evaporation of the condensation, since there were four small ventilation holes in the container sides. The first floor had limited ventilation, and in the hold, the ventilation was very poor.

In the container located on the deck, the water retention capacity was reduced at low temperatures, and the bags in the top region gained moisture, as shown in Table 1. In the other two containers, the temperature decreased slowly, and consequently, the water retention capacity was higher, the tendency being for the water in the environment to reach relative humidity equilibrium. This water, in vapor form, rises by convection, becomes cold, and forms condensation because of the high temperature gradient between the headspace and the cargo and between the headspace and the external environment.

Palacios-Cabrera et al. *(11),* testing OA production in coffee beans, observed condensation inside the desiccator walls when incubated at alternating temperatures of 15 and 25°C for 12 h each. There was coalescence, and the water dripped onto the coffee surface. This suggests that some regions of the cargo reached water activity values higher than 0.90, especially where the water drips and condensation runs. This water migrates in the form of vapor pressure dissolved in the interbean air, and the tendency is to reach equilibrium with the rest of the cargo. According to Palacios-Cabrera et al. *(11),* OA formation by toxigenic fungi occurs at water activity values higher than 0.85. The International Coffee Organization *(4)* reports that the most significant risks during coffee transportation and storage for development of molds and OA occurrence are improper drying and rewetting. Therefore, it is recommended that the moisture content of coffee not exceed 12.5% (wet base) at any point and that rewetting be avoided. This has been discussed elsewhere *(4).*

Another interesting point is the moisture gain for different vapor pressure gradients between the surface of the beans and the container headspace. This is like a grain isothermal adsorption study in containers. Analyzing the data for relative humidity in the headspace in Figure 2, it can be observed that at the end of the journey, which took approximately 251 h, the equilibrium relative humidity reached 80 to 82%, and in some cases, it was higher than 85%. From earlier data of Palacios-Cabrera et al. *(12),* where there was a gain in moisture content in coffee stored under conditions of constant (25°C) and alternating temperatures (15 and 25°C), it can be observed that there were increases in moisture content on a wet base of about 2.1 and 2.5%, respectively, in a period of 8 days. In the present study, the journey took 251 h, suggesting that in this period, the gain in moisture content had a real effect on the gradient difference as shown in Table 1, especially in the top layer of coffee bags on the deck. It was concluded that there was an increase in moisture content in coffee placed on the top and near the lateral walls of the containers. We believe that this increase was exclusively due to the differential in the vapor gradient between the lateral walls and the headspace as well as to the temperature. The coadjuvant effect of temperature in this case is evident because of the greater increase in moisture content of the coffee beans from the container on the deck compared with those on the first floor and in the hold. This was because the cargo temperature on the deck was lower than the temperature on the first floor and in the hold, favoring a higher absorption capacity of moisture on the deck. Sharp *(19)* and Pixton *(17)* verified this condensation on maritime routes when there were drastic temperature changes, mainly when the transport of grains went from a warm region to a cold one (sweating container).

Tables 3 and 4 present the OA concentrations in the coffee in the conventional and prototype containers, respectively, at the beginning and end of the voyage. According to Tables 3 and 4, there was a slight increase in OA production during transportation, especially at the top

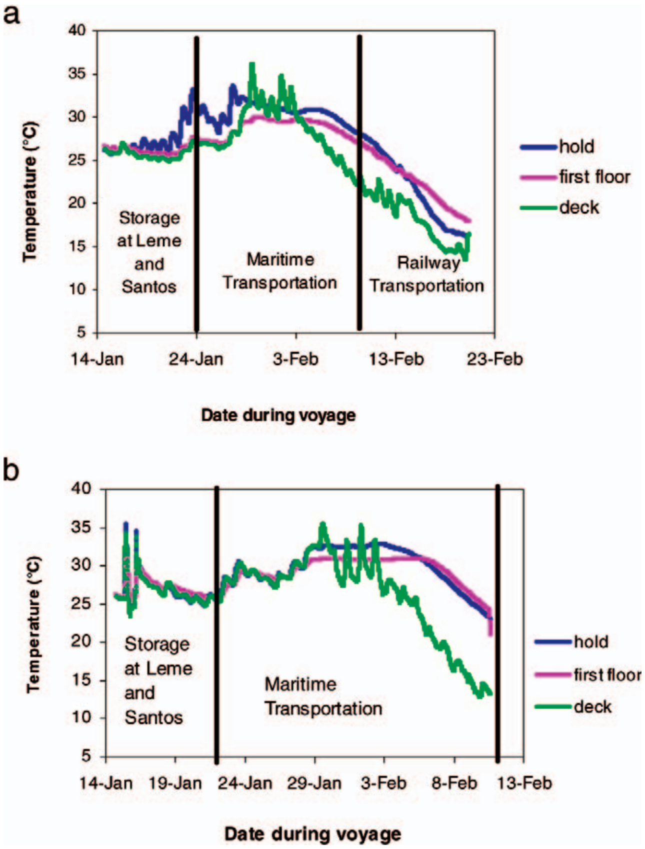

FIGURE 5. *Temperature kinetics at the top of conventional and prototype containers from Brazil to Italy: (a) conventional container and (b) prototype container.*

of the container located on the deck, close to the headspace. In this location, the temperature oscillation was more drastic, and consequently, the humidity diffusion inside the container was more dynamic than on the other decks, mainly during the sea voyage. A similar situation occurred at the top of the prototype containers, which presented higher OA production. From the results presented, the first floor would appear to be the most appropriate location for container transportation, since the temperature oscillation was less drastic, and the interbean microenvironment was less adequate for fungal growth and toxin production.

Figure 5 shows the temperature kinetics at the top of conventional and prototype containers. In spite of the prototypes not being allowed to follow the inland trajectory by train to Trieste, in general, the tendencies of temperature kinetics for the conventional and prototype containers were similar, although changes in temperature from the prototype located on the deck were more drastic and had happened already during maritime transportation. However, the prototypes were shown to be of good use when carrying out further studies on coffee transportation at pilot levels.

Because the temperature changes drastically affected container condensation, it is recommended that the unloading of coffee in importer countries be as quick as possible, since condensation will increase, and if the spores of toxigenic fungi are present in the coffee beans, they will develop and produce toxin.

We agree with the recommendations given by the International Coffee Organization report *(4)* on coffee transportation, but we also add to them the following recommendations, in light of the present study. (i) Avoid leaving stuffed containers for an extended period of time exposed to full sunshine. Preferably, use shaded areas, or put another container on top. The roof of an unprotected container can reach temperatures of over 80°C. Cooling off during the night results in condensation. (ii) Avoid rewetting by covering bags during transport. Cardboard, single-side corrugated and waxed on the inside, has proved to be the best protection against condensation for bags in containers, but kraft paper has also been used successfully (in our experiment, kraft paper was not sufficient to avoid water migration to the coffee bags). Line the sides of the containers for bags with water-absorbent paper. (iii) Keep the ventilation holes in the containers free—do not cover them with tape. (iv) Watch for changes in moisture and temperature of coffee during a sea voyage. Although shipping transport trials have proven that not very much happens to the moisture or temperature of coffee during a sea voyage (in our trial, changes in relative humidity and temperature started at the end of the maritime journey [Fig. 2]), for longer-distance voyages, such as from Brazil to Japan, these changes might be more drastic. (v) Avoid unprotected stowage on the deck (top layer), and stow away from boilers and heated tanks or bulkheads. (vi) Preferably, use direct shipment, and avoid trans-shipment when possible. Trans-shipment, especially in ports in northern zones, increases the risk of condensation. (vii) In trans-shipment ports, avoid leaving stuffed containers for an extended period exposed to full sunshine. Preferably, use a shaded area, or put another container on top. The roof of an unprotected container can reach temperatures of over 80°C. Cooling off during the night results in condensation. (viii) Upon arrival of the ocean vessel, the coffee must be received and discharged as soon as possible. Avoid unnecessary delays once the coffee has arrived. Transport trials have proven that big differences in temperature during day and night cause significant risks of condensation and thus of rewetting. (ix) The moisture level should not exceed 12.5% anywhere, from the point where the coffee leaves to the point at which the coffee is roasted.

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