International Supply Chain Handling Practices and the Quality of Heat-treated, White Oak Veneer Logs

Zhangjing Chen,[a,*] Marshall White,[a] Ron Mack,[b] Daniel Rider,[c] Vijay Reddy,[d] and Susan O'Neill [e]

The most promising alternative to the methyl bromide fumigation of exported logs is steam-heating the log in a vacuum. Research has confirmed that steam heating to 56 °C for 30 minutes kills all viable propagules of oak wilt pathogen (*Bretziella fagacearum)* in the sapwood of oak logs. The purpose of this study was to determine whether this heat-treatment method has any effect on the quality or value of white oak veneer logs shipped between the US and EU. Seventeen steam- and vacuum-treated and seventeen untreated control logs were shipped from Baltimore, Maryland to the Czech Republic, for processing into veneer, between December 2021 and February 2022. The treated and untreated logs were sawn into flitches, soaked in hot water vats, sliced, dried, and the veneer from each log was graded for quality. Each log was assigned a value based on the veneer quality and yield. The average value of treated log was 1,547 €/m³, and the average value of the untreated logs was 1,539 €/m³. The null hypothesis was statistically confirmed. Therefore, it is concluded that the 56 °C/30 min, sapwood heat treatment using vacuum and saturated steam had no adverse impact on the value of the white oak veneer logs.

DOI: 10.15376/biores.18.2.3802-3814

Keywords: Logs; Export; Non-Chemical; Phytosanitation; Treatment; Supply chain

Contact information: a: Department of Sustainable Biomaterials, Virginia Tech Blacksburg, VA, USA; b: Otis Laboratory, USDA APHIS PPQ, Buzzards Bay, MA, USA; c: Maryland Department of Natural Resources, Annapolis, MD, USA; d: Danzer Veneer Americas Inc., Darlington, PA, USA; e: Executive Director, Upper Shore Regional Council, Chestertown, MD, USA;
** Corresponding author: chengo@vt.edu*

INTRODUCTION

One of the most common uses of methyl bromide (MB) fumigation is the pre-shipment and phytosanitation treatment of logs for export. Methyl bromide has been used to control the spread of the oak wilt fungus. Methyl bromide has been controlled as a class 1, ozone-depleting chemical. Under the Montreal Protocol, its exemption uses are expected to stop, when feasible, alternative treatments are developed. As the state of Maryland instituted more stringent air quality control requirements, the Port of Baltimore ceased methyl bromide fumigation in 2016 (Hafner 2021). The Maryland Department of Natural Resources estimates that because of this, the state lost a $15 million log export market. Other states in the US are increasingly restricting the use of this fumigant. As of December 31, 2020, the EU prohibited shipment of methyl bromide fumigated, oak logs, with bark, from the US to EU countries (Bragard *et al.* 2020).

Over the past 9 years, researchers at Virginia Tech have partnered with the USDA's Animal and Plant Health Inspection Service (USDA APHIS) and the USDA Forest Service

to develop an alternative, non-chemical, phytosanitary treatment, based on heating log sapwood using vacuum and saturated steam. They recently confirmed that all oak wilt fungus *Bretziella fagacearum* was killed when the sapwood (5 cm depth) is heated to 56 °C and held for 30 min (Juzwick *et al.* 2019). Two additional studies, in cooperation with Danzer Veneer Americas Inc., confirmed that this heat treatment process did not affect the quality of red oak, walnut, cherry, hickory, and yellow-poplar veneer logs during domestic shipments (Chen *et al.* 2014, 2017). This was based on comparing the yield and quality of the veneer sliced from untreated and treated logs. These domestic shipments were less than 3 days in length and used only one mode of handling and shipping, in open trailers over the road. However, international supply chains for log shipments are 4 to 8 weeks in transit and multi-modal, including containerized, over the road, over water, and inter-modal rail shipments. Because of this, there are significantly more environmental and climactic changes, all of which could impact log quality and value. Bragard *et al.* (2020) identified vacuum steam as a leading treatment alternative for oak wilt, under development, and suggests that "technical hurdles must be overtaken before these alternatives can be implemented". These technical hurdles are further referenced in the minutes of the 3rd meeting of the European Food Safety Authority (EFSA) Working Group web meeting (Annex 1, item 28, 16 Sept 2020) (European Food Safety Authority 2020) as "only limited investigation has been made of the effect of vacuum steam treatment on log quality. More quality testing is required to satisfy concerns of the EU mill industry, which would include shipping vacuum steam-treated logs to the EU for milling into veneer." Hardwood decorative veneers are very thin slices of wood (0.50 mm thick) that are obtained from flitching, and slicing or peeling, logs. Veneers vary in wood species, grain appearance, colors, and textures, all of which impact the value of the veneer and the log from which it is manufactured. In current, international markets, white oak veneer logs are highly valued.

The objective of the proposed study was to determine whether the species, targeted, steam/vacuum, 56 °C/30 min, (5 cm) sapwood, heat treatment (HT) schedule, adversely affects the quality and value of white oak veneer logs that move through the extended international supply chain between the US and the EU.

TESTING METHODS

The commerce of high value veneer logs between North America and EU countries is seasonal. It extends from October 1 to April 30 so that containers of logs are not exposed to high temperatures during shipment. Summer temperatures in the Northern Hemisphere will degrade log quality during shipment. The following chronology documents the supply chain through which the logs passed from the time of harvest to delivery and processing in the Czech Republic.

November 8, 2021 – Log Delivery to Elkton, Maryland

Thirty-four (34) white oak veneer quality logs were delivered to Polo Pallet/Mill Creek lumber company, 1726 East Old Philadelphia Road, Elkton, Maryland (USA). The logs were purchased by the Grant from Danzer Veneer Americas from their log yard in Edinburgh, Indiana (USA). The logs were purchased by Danzer between September 2, 2021 and October 31, 2021 and harvested in the mid-western US. The logs were shipped on open trailers to Edinburgh and once accumulated, they were shipped on open trailers to Elkton.

The logs were all 2.5 m long. The small end diameter (SED) ranged from 35.6 to 59.7 cm, and the large end diameters (LED) were from 39.4 to 78.7 cm. The logs were randomly separated into two groups of 17 each, as shown in Fig. 1. One group was used for HT and the other were untreated control logs. An attempt was made to have logs of a similar size distribution in each group. Tables 1 and 2 contain the size and volume, based on the Doyle log scale, of the logs in each group. The logs were placed into temporary storage using plastic tarpaulin. The logs were end-coated with Anchorseal, and 10 × 15 cm metal connector plates were applied to the end of the logs and located, depending on visible splits.

Fig. 1. Logs were sorted into two groups of approximately the same size distribution, plated, and end coating applied

Table 1. Description of the Treated, 249 cm Long, White Oak Logs

	ID Number	SED (cm)	LED (cm)	Volume (m^3 Doyle)
1	562154	48.3	68.6	0.231
2	610431	39.4	50.8	0.142
3	562381	48.3	57.2	0.231
4	562658	39.4	61.0	0.142
5	562657	36.8	45.7	0.118
6	568046	45.7	53.3	0.231
7	563479	44.5	47.0	0.198
8	561149	54.6	68.6	0.340
9	610457	36.8	45.7	0.118
10	561558	44.5	58.4	0.198
11	610468	40.6	59.7	0.170
12	564099	35.6	41.9	0.118
13	263476	45.7	52.1	0.231
14	262513	41.9	50.8	0.170
15	566885	38.1	44.5	0.118
16	562379	53.3	62.2	0.198
17	558810	55.9	66.0	0.340
Total volume (m^3)				3.29
Total Est. Weight (kg)				7598.7

November 9 to 16, 2021 – Log Treatments

Steam and vacuum heat treatments of the 17 logs began on November 9th in groups of 3 or 2 logs per treatment. Figure 2 shows the treatment system layout with generator and the 6 m trailer containing the vacuum chamber, vacuum pump, electric boiler, process controller, and data acquisition system.

Fig. 2. The electric generator and portable steam/vacuum treating system at Polo Pallet/Mill Creek Lumber, Elkton, Maryland

Table 2. Description of the Untreated, 249 cm long, White Oak Logs

	ID Number	SED (cm)	LED (cm)	Volume (m^3 Doyle)
1	610440	38.1	53.3	0.142
2	561625	43.2	58.4	0.198
3	568106	35.6	39.4	0.118
4	568038	44.5	48.3	0.231
5	562659	36.8	49.5	0.118
6	561596	43.2	61.0	0.198
7	620545	58.4	66.0	0.382
8	566958	36.8	52.1	0.118
9	566437	39.4	59.7	0.142
10	610437	41.9	63.5	0.170
11	563477	43.2	44.5	0.198
12	561637	40.6	55.9	0.170
13	561627	59.7	78.7	0.425
14	561414	44.5	61.0	0.170
15	562157	59.7	67.3	0.425
16	562378	43.2	62.2	0.198
17	562155	41.9	55.9	0.170
Total Volume (m^3)				3.57
Total Est. Weight (kg)				8241.0

Portable Phytosanitation System

The vacuum chamber has internal dimensions of 2.6 m length × 1.52 m width × 1.52 m height. Figure 3 shows the interior of the trailer with the vacuum chamber in the background. The treating system includes an electric boiler, vacuum pump, and a temperature and pressure control and data acquisition system. For equipment specifications, see Juzwick *et al.* (2020). Twenty-four omega, K type, thermocouples were connected from the chamber to the data acquisition system to permit recording temperatures. LabVIEW (National Instrument, version 2014, Austin, TX, USA) is commonly used for data acquisition and recording. Real time temperature profiles were recorded, and cycle times were determined.

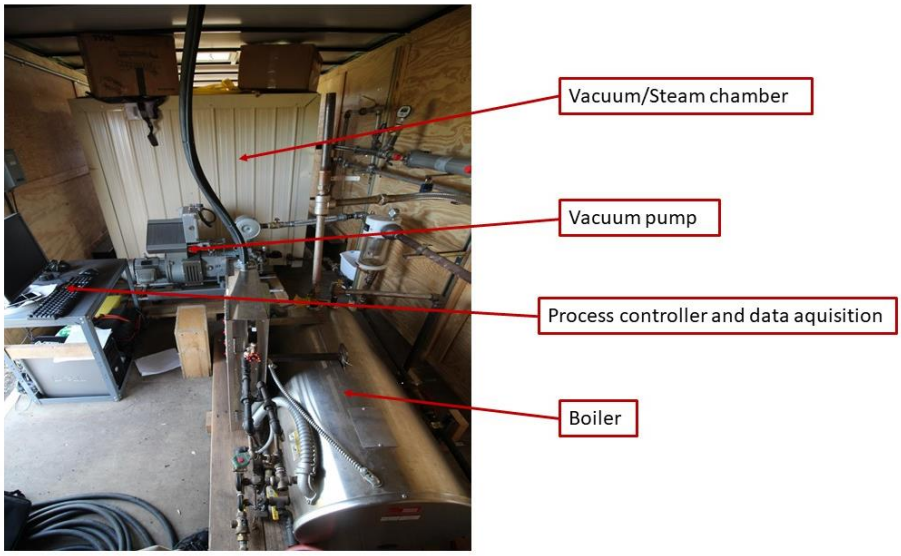

Fig. 3. Photograph showing the interior of the 6-m-long trailer and components of the vacuum/steam treating system

The Steam and Vacuum Treatment Cycles

The bark and wood, to a depth of 5 cm below the inner bark of the log, was heated to 56 °C, and this temperature was maintained for 30 minutes, using saturated steam at 90 °C, injected into the vacuum chamber at an initial pressure of 100 mm Hg. The sapwood in all logs was less than 5 cm thick; therefore, all sapwood was treated to, at least, the target temperature. The chamber temperature was controlled to 85 °C +/- 3 °C throughout the treatment cycles. The average pressure during treatment was about 500 mm Hg throughout the cycle. Log temperatures were measured using thermocouples placed 5 cm below the inner bark (phloem) to a depth of 200 mm into the ends of each log. According to research by Juzwik *et al.* (2020), the temperature at this depth into the end of the log, best replicates the temperature anywhere along the log length at the same depth below the log surface. The thermocouples were placed into 3 mm diameter holes, and then the holes were plugged with plumber's putty. In the largest log two thermocouples were placed in the ends at the 5 cm depth and at different locations around the circumference. Figure 4 shows logs in the chamber immediately after steam and vacuum treatments. Thermocouple placement (indicated by four white dots on the ends of the logs) is shown in the figure. The log in each treatment, that was the slowest to heat, determined the cycle time. Other logs in the treatment were hotter. Log size in each treatment varied and, in some treatments,

noticeably. Figure 5 shows a typical chamber and log temperature profile during a steam and vacuum treatment. While log 510468 determined the cycle time to 56 °C and held for 30 min, logs 561558 and 610431 were at 62 °C and 64 °C, respectively, at the 5 cm depth at the end of the cycle.

Fig. 4. Logs after treatment in the steam/vacuum chamber showing end plates and thermocouples

After treatment, the logs were placed back into outside storage, under plastic tarpaulin. Care was taken during the test shipment that the untreated (control) and treated logs were always handled and stored in a similar manner.

Table 3 contains the energy consumption, initial log temperatures, and the duration of each of the six treatments. Initial log temperatures ranged from 0 °C to 14 °C. Total cycle times ranged from 7.9 to 11.7 h.

December 21 and 22, 2021 - Logs Placed into Two, 20-foot Freight Containers

The treated logs showed some sapwood mold prior to shipment. On the 21st December 2021, the 17 untreated logs were loaded into a 20-foot container and on 22nd December 2021, the 17 treated logs were loaded into a separate 20-foot container and both were shipped to the Port of Baltimore.

Permission for shipping the treated and untreated logs to Melnik, Czech Republic was given by the Central Institute for Supervising and Testing in Agriculture, Division of Plant Health in the Czech Republic. This was codified in the Letter of Authority. Based on this, the USDA APHIS PPQ (Plant Protection and Quarantine) issued two phytocertificates, prior to shipment through the Port of Bremerhaven, Germany.

January 25, 2022 – Logs Arrive at Danzer Bohemia – Dyharna, Melnik, Czech Republic

The two containers of logs arrived at the Danzer Bohemia facilities in Melnik on January 25, 2022. The containers were opened, and the logs were removed from the containers, inspected, and set into the log yard for temporary storage. Most logs exhibited white mold on all surfaces. The treated logs exhibited more surface mold than the control logs, as shown in Fig. 6. The staff of Danzer Bohemia confirmed that mold often occurs on logs and the mold observed, was typical.

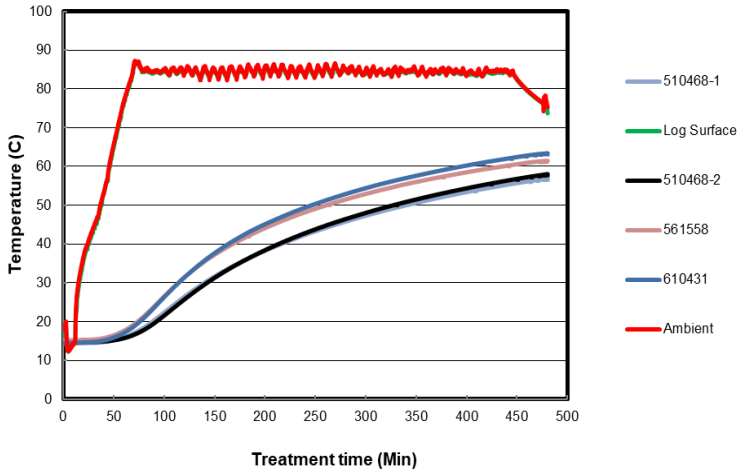

Fig. 5. Typical, chamber and log temperature profiles during the steam and vacuum heat treatment of white oak veneer logs

Table 3. Energy Consumption, Steam and Vacuum Cycle Time, and Initial Temperatures for Log Treatments

Test	Date	Log 1 Lower, right	Log 2 Top	Log 3 Lower, left						
		Log Number			Log Temp (°C)	Vacuum Time (min)	Steam Time (min)	Hold Time (min)	Total Time (min)	Energy Use (kwh)
1	9-Nov	566885	558810	562379	10	10	658	30	698	54.83
2	11-Nov	562657	568046	564099	5	11	505	30	546	59.39
3	12-Nov	610431	610468	561558	14	9	437	30	476	58.16
4	13-Nov	610457	562381	562154	6	9	504	30	543	78.14
5	15-Nov	561149	562513	562658	7	8	699	30	737	77.04
6	16-Nov		563476	563479	0	9	578	30	617	41.92

Fig. 6. Logs being inspected after delivery to Danzer Bohemia, Melnik, Czech Republic on January 25, 2022

February 4 to 15, 2022 - Processing of the Logs into Veneer

Table 4 contains the processing schedule. This includes, end trimming, debarking, flitching of the logs, soaking of the flitches in a hot water vat, followed by slicing and drying the veneer.

End trimming, debarking, and flitching

The end trimming (about 1.0 cm each end) was performed with a chain saw to remove the metal plates from the ends of the logs.

The logs were debarked with a DAWA - double crossing head, debarker (BSY Industry Co., Shandong, China). The logs were flitched on the band saw. There were two flitches per log.

Soaking in a vat

All treated and untreated flitches were placed together, into a hot water vat for 48 h at 80 °C prior to slicing.

Planing, slicing, and drying

The front and back of the flitch were flattened into two parallel surfaces. The vertical slicer sliced the veneer to a thickness of 0.54 mm. The veneer dryer was a continuous flow, Babcock BSH Thermojet (Babcock-BSH, Bad Hersfeld, Germany). The initial temperature was 125 °C and it increased to 135 °C. The flow rate was 45 m/min and the final target moisture content of the veneer was 10% to 14%.

Figure 7 shows images of typical white oak flitches prior to soaking in the hot water vats. The surface mold had no effect on wood quality and color. The heartwood color variation was typical of white oak. A few logs from both the treated and untreated logs showed some past insect activity and some dirt embedded in the surface from handling and storage. No live or dead insects were found in any of the treated or untreated logs. Both sets of logs exhibited the typical variation in color and quality.

Fig. 7. Typical flitches sawn from the white oak veneer logs

Table 4. The Schedule for Processing the White Oak Veneer Logs into Veneer

Date in 2022	Process	Location	Actions taken
1/31 to2/2	Inspection	Log Yard	Photo documentation of each log
2/4	Cross Cut	Log Yard	Cross cut ends and mark saw pattern
2/7	Flitching	Saw Mill	Saw into flitches for flat slicing
2/8 and 2/9	Hot Water	Vats	Soften logs for slicing
2/10	Planning	Slicing Plant	Create smooth flat surface for slicing
2/10	Slicing	Slicing Plant	Slicing and drying of the veneers
2/10	Drying	Slicer/Dryer 1	Partwise photos if necessary
2/15	Clipping	Clipping Line 2	Clipping of the veneer bundles
2/15			Photo documentation of veneer bundles
1/15			Remove samples from each Flitch
2/24	Grading	Grading Line	Grading of clipped samples

RESULTS AND DISCUSSION

There was a one month delay between treatment and shipping. This is not typical of such supply chains. Unfortunately, international supply chains were severely disrupted during the Winter of 2021/2022. This led to significant delays in ship scheduling. During the period of log storage, some mold growth was observed on both treated and untreated logs. Danzer Bohemia noted that the door seams of the container with treated logs was sealed with duct tape. When, why and by whom this was done is unknown. The lock seal on the container door was never compromised. Further, it is not known where on the container ship, these containers were placed. It is therefore possible that the environments within the two containers were different. These conditions could have contributed to the difference in mold growth observed. Additional test shipments are planned to determine to what extent the heat treatment may contribute to mold growth on the surface of the log.

February 24, 2022 – Grading of Veneer Samples

Figure 8 shows bundles of typical veneer samples obtained after drying but before clipping. Three samples from each bundle, from each flitch, were removed for grading. The veneer was graded as door veneer because of the relatively short length of the logs. Shorts are veneers after clipping less than 2.05 m long. There are no recognized standards for veneer grades. Danzer has a customized grading procedure that will change depending on market preferences. The veneer grades used are described below in order of diminishing value from Door AB to Shorts BC/C. A "pip" is a small bubble or protrusion from the veneer surface:

Door AB, clean, few sound pips or occasional sound knots allowed, normal crown structure, medium color (no red, no green), no open defects, max. 30% quarter grain;

Door B, wild structure, sound and black pips allowed, some sound knots allowed, off colors allowed, higher share of quarter grain and half-crown grain accepted;

Door BC/C, single bundles, with medium to heavy flakes, with sap wood, open defects, off colors;

Shorts AB/B 0.60 m to 2.05 m, clean, sound shorts, crowns and quarter grains, color limited;

Shorts BC/C 0.60 m to 2.05 m, wild structure, flakes, sap, off colors, open defects.

Fig. 8. Photographs of typical white oak veneers from flitches from the treated and untreated logs

The visual grades depend on veneer color, grain, the number and size of tree growth related defects, *etc*. Important for this study, was that the grader of the veneer was not aware of whether veneer from the treated or untreated logs, was being graded.

Table 5. Log Volume, Veneer Surface Area, Veneer Yield, Veneer Value, and Log Value for Treated Logs

Log Number	Log Volume (m^3)	Veneer Surface Area (m^2)	Veneer Yield (m^2/m^3)	Veneer Value (€/m^2)	Log Value (€/m^3)
W558810	0.529	340	643	1.67	1,074
W561149	0.621	536	863	1.45	1,251
W561558	0.425	384	904	1.94	1,754
W562154	0.480	420	874	1.94	1,696
W562379	0.399	358	898	1.92	1,725
W562381	0.461	463	1,005	2.02	2,030
W562513	0.349	465	1,331	1.96	2,609
W562657	0.272	203	746	1.54	1,150
W562658	0.333	231	694	1.41	979
W563476	0.407	412	1,013	2.22	2,248
W563479	0.382	245	642	1.86	1,194
W564099	0.263	139	529	1.51	799
W566885	0.302	368	1,217	2.02	2,458
W568046	0.434	225	518	2.19	1,135
W610431	0.349	301	862	2.08	1,793
W610457	0.287	240	838	1.26	1,055
W610468	0.350	272	776	1.67	1,296
Average	6.643	5,602	843	1.83	1,547

According to the staff at Danzer Bohemia, the color and quality of the veneer from both the treated and untreated logs were typical and were not distinguishable from both sets of logs. The yield of veneer and a value of the veneer from each log was determined from the grade of the veneer and current market in Euros/m². From these data a log value, in terms of Euros/m³ of log volume, was calculated. More detail regarding this procedure for assigning log value can be found in Chen *et al.* (2022). Log volumes, veneer surface areas, veneer yields and values, and log values are shown in Tables 5 and 6, respectively, for the treated and untreated (control) logs.

Table 6. Log Volume, Veneer Surface Area, Veneer Yield, Veneer Value, and Log Value for the Untreated Logs

Log Number	Log Volume (m³)	Veneer Surface Area (m²)	Veneer Yield (m²/m³)	Veneer Value (€/m²)	Log Value (€/m³)
W561414	0.443	307	693	1.83	1,268
W561596	0.416	301	723	1.68	1,215
W561625	0.382	343	899	2.09	1,879
W561627	0.748	652	871	1.46	1,272
W561637	0.373	331	888	2.08	1,847
W562155	0.399	280	703	1.95	1,370
W562157	0.679	519	765	1.88	1,437
W562378	0.434	439	1,012	1.89	1,912
W562659	0.323	239	739	1.52	1,123
W563477	0.373	336	900	2.12	1,909
W566437	0.341	252	738	1.58	1,166
W566958	0.308	208	675	2.10	1,418
W568038	0.399	402	1,009	2.18	2,199
W568106	0.236	172	730	1.45	1,059
W610437	0.407	293	719	1.35	971
W610440	0.333	273	820	1.89	1,549
W620545	0.679	692	1,020	2.12	2,161
Average	0.430	355	830	1.85	1,539

Table 7. Statistical Test of Hypothesis Comparing, the Average Log Volume, Veneer Surface Area, Veneer Yield, Veneer Value, and Log Value for the Treated and Untreated Logs

	Log Volume (m³)	Veneer Surface Area (m²)	Veneer Yield (m²/m³)	Veneer Value (€/m²)	Log Value (€/m³)
Treated logs	6.643	5,602	843	1.83	1,547
Untreated logs	7.273	6,040	830	1.85	1,539
Average	6.958	5,821	837	1.84	1,543
Treated *vs.* untreated logs			1.6%	-1.0%	0.5%
T Test Results					
P Value, Two Tail	0.3763	0.5648	0.6644	0.7586	0.8608

Table 7 summarizes these data and provides a statistical test of experimental hypothesis based on the Students T test (Excel version 1808 Microsoft, Seattle, WA, USA) and assuming equal variance.

The statistical analysis confirmed the null hypothesis that there is no difference in average log volume, veneer surface area, veneer yield, veneer value, and log value between the treated and untreated logs.

CONCLUSIONS

Based on these data and the observations and comments from the staff at Danzer Bohemia-Dyharna, the steam and vacuum heat treatment of the white oak veneer logs at 56 °C for 30 min at 5 cm below inner bark, had no effect on log quality and log value when the logs were shipped through the international supply chain between the US and the Czech Republic.

REFERENCES CITED

Bragard, C., Dehnen-Schmutz, K., Di Serio, F., Jacques, M. A., Miret, J. A. J., Justesen, A. F., MacLeod, A., Magnusson, C. S., Milonas, P., Navas-Cortes, J. A., *et al*. (2020). "Commodity risk assessment of oak logs with bark from the US for the oak wilt pathogen *Bretziella fagacearum* under an integrated systems approach," *EFSA Journal* 18(12), article ID e06352. DOI: 10.2903/j.efsa.2020.6352

Chen, Z., White, M. S., and Mack, R. (2017). "Evaluation of the steam and vacuum process on hardwood veneer logs for export," *European Journal of Wood and Wood Products* 75, 911-918. DOI: 10.1007/s00107-016-1138-7

Chen, Z., White, M., and Mack, R. (2014). *Using Vacuum and Steam to Sanitize Veneer Logs for Export*, USDA APHIS PPQ CPHST, Raleigh, NC, USA.

Chen, Z., and White, M. (2022). *Field Demonstration of Vacuum Steam Treatment to Eliminate Trade Barriers for Maryland Log Exports*, Department of Sustainable Biomaterials, Virginia Tech, Blacksburg, VA, USA.

European Food Safety Authority (2020). "Scientific panel on plant health," minutes of: the *3rd Meeting of the Working Group on US Oak Logs with System Approach for Oak Wilt*, WEB-conference, (https://www.efsa.europa.eu/sites/default/files/wgs/plant-health/wg-us-oak-logs-system-approach-oak-wilt.pdf), EFSA, Parma, Italy.

Hafner, M. 2021. "Methyl bromide fumigation at Port of Baltimore" National Small Business Environmental Assistance Program (SBEAP), "Methyl bromide fumigation operation history, current status and lessons learned in air permitting," webinar, May 19, 2021.

Juzwik, J., Yang, A., Chen, Z., White, M., and Mack, R. (2019). "Vacuum steam treatment eradicates viable *Bretziella fagacearum* from logs cut from wilted *Quercus rubra*," *Plant Disease* 103(2), 276-283. DOI: 10.1094/PDIS 07-18-1252-RE

Juzwik, J., Yang, A., Heller, S., Moore, M., Chen, Z., White, M., Wantuch, H., Ginzel, M., and Mack, R. (2020). "Vacuum steam treatment effectiveness for eradication of the thousand cankers disease vector and pathogen in logs from diseased walnut trees," *Journal of Economic Entomology* 114(1), 100-111. DOI: 10.1093/jee/toaa267

Article submitted: August 23, 2022; Peer review completed: October 16, 2022; Revised version received: March 27, 2023; Accepted: March 30, 2023; Published: April 14, 2023.
DOI: 10.15376/biores.18.2.3802-3814