ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.28, n.9, e277729, 2024
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v28n9e277729
Original Article

Noise mapping technique for an unrefined sugar cane processing factory[1]

Técnica de mapeamento de ruído para uma fábrica de processamento de rapadura

Juan D. Alvarez-Carpintero[2*], Robinson Osorio-Hernández[2] & Jesús H. Camacho-Tamayo[2]

[1] Research developed at Universidad Nacional de Colombia, Bogotá, Colombia
[2] Universidad Nacional de Colombia/Facultad de Ingeniería/Departamento de Ingeniería Civil y Agrícola, Bogotá, Colombia

HIGHLIGHTS:

The application of a mapping technique for sounds characterizes the environmental situation in a precise way.
The gathered sound levels do not present changes in their measured values for any of the measured work shifts.
The time-weighted maximum noise levels do not exceed the recommended limits established for worker safety.

ABSTRACT: Noise monitoring in production factories is a tool used to visualize and address sound level problems. The objective of this study was to characterize the current situation inside an unrefined sugar cane factory located in Caparrapí, Colombia, through mapping techniques and to determine alternatives, if necessary. For this purpose, the allowed duration exposure for current sound levels was calculated, along with the daily noise dose experienced by the workers at 69 points inside the factory, considering each production section: packaging, molding, weighing, and evaporation. The analysis revealed that the factory generally maintains noise levels below the allowed maximum. However, the results show that there are some points with high sound levels, mainly caused by the reflection of sound by walls, particularly in areas such as the molding and weighing sections, where the noise dose reaches approximately 75 dB. Nevertheless, it can be observed that the factory presents noise levels under the allowed maximum, with certain areas that could present higher levels with changes in the activities being performed. These findings suggest that targeted interventions in specific areas could further improve the overall noise levels within the factory environment.

Key words: brown sugar, sound level, time-weighted average, acoustic environment, exposure time

RESUMO: O monitoramento de ruído em fábricas de produção é uma ferramenta usada para visualizar e abordar problemas de níveis sonoros. O objetivo deste estudo foi caracterizar a situação atual dentro da fábrica de cana-de-açúcar não refinada, localizada em Caparrapí, Colômbia, por meio de técnicas de mapeamento e determinar alternativas, se necessário. Para isso, foi calculada a exposição permitida para os níveis sonoros atuais, juntamente com a dose diária de ruído experimentada pelos trabalhadores em 69 pontos dentro da fábrica, divididos em cada seção de produção: embalagem, moldagem, pesagem e evaporação. A análise revelou que a fábrica geralmente mantém níveis de ruído abaixo do máximo permitido. No entanto, os resultados mostram que existem alguns pontos com níveis de som elevados, principalmente ocasionados pela reflexão nas paredes, particularmente em áreas como moldagem e seções de pesagem, onde a dose de ruído atinge aproximadamente 75 dB. No entanto, pode-se observar que a fábrica apresenta níveis de ruído abaixo do máximo permitido, com certas áreas que poderiam apresentar níveis mais altos, com mudanças nas atividades realizadas nela. Essas descobertas sugerem que intervenções direcionadas em áreas específicas poderiam melhorar ainda mais os níveis gerais de ruído dentro do ambiente da fábrica.

Palavras-chave: rapadura, nível sonoro, média ponderada no tempo, ambiente acústico, tempo de exposição

• Ref. 277729 – Received 18 Aug, 2023
* Corresponding author - E-mail: juadalvarezcar@unal.edu.co
• Accepted 27 Mar, 2024 • Published 06 May, 2024
Editors: Ítalo Herbet Lucena Cavalcante & Hans Raj Gheyi

Introduction

Brown sugar, known in Spanish as "panela," is also referred to as non-centrifugal cane sugar (NCS). It is a natural sweetener derived from the concentration of sugar cane juice in facilities known as "trapiches." NCS is available in various forms and sizes (Jaffé, 2015; Mesías et al., 2020; Asikin et al., 2023).

Non-centrifugal cane sugar production in Colombia is characterized by a lack of technification systems for cane production and subsequent processing (Solís-Fuentes et al., 2019; Velásquez et al., 2019; Polo-Murcia et al., 2022). In response to production challenges and the need to increase NCS production levels in Colombia, production facilities known as "centrals," with capacities of up to 250 kg h^{-1}, were established (FEDEPANELA, 2019, Mendieta et al., 2016). Research in Colombia has also focused on determining optimal working conditions for factory operators (Alvarez-Carpintero et al., 2021). However, while previous studies have examined noise in rural production sites in other countries (García et al., 2017; Quezada-Moreno et al., 2021; González-Campaña & Zúñiga-Cabrera, 2022), there has been limited investigation into these characteristics within industrial factory settings.

Previous studies have mapped urban sound levels using similar techniques to identify risk zones surpassing suggested maximums (Murphy et al., 2020; Murphy & King, 2022), and sound levels have been mapped inside production factories, such as concrete production factories (Ahmed & Gadelmoula, 2020) and fatty acid plant areas (Hasibuan et al., 2020), where the main problems are noise reflection by walls and the sound levels produced by the production equipment.

To generate a complete study on a non-centrifugal sugar cane factory located in Caparrapí, Colombia, this article has the objective of characterizing the current situation inside this unrefined sugar cane factory located in Caparrapí, Colombia, through mapping techniques and determining alternatives, if necessary.

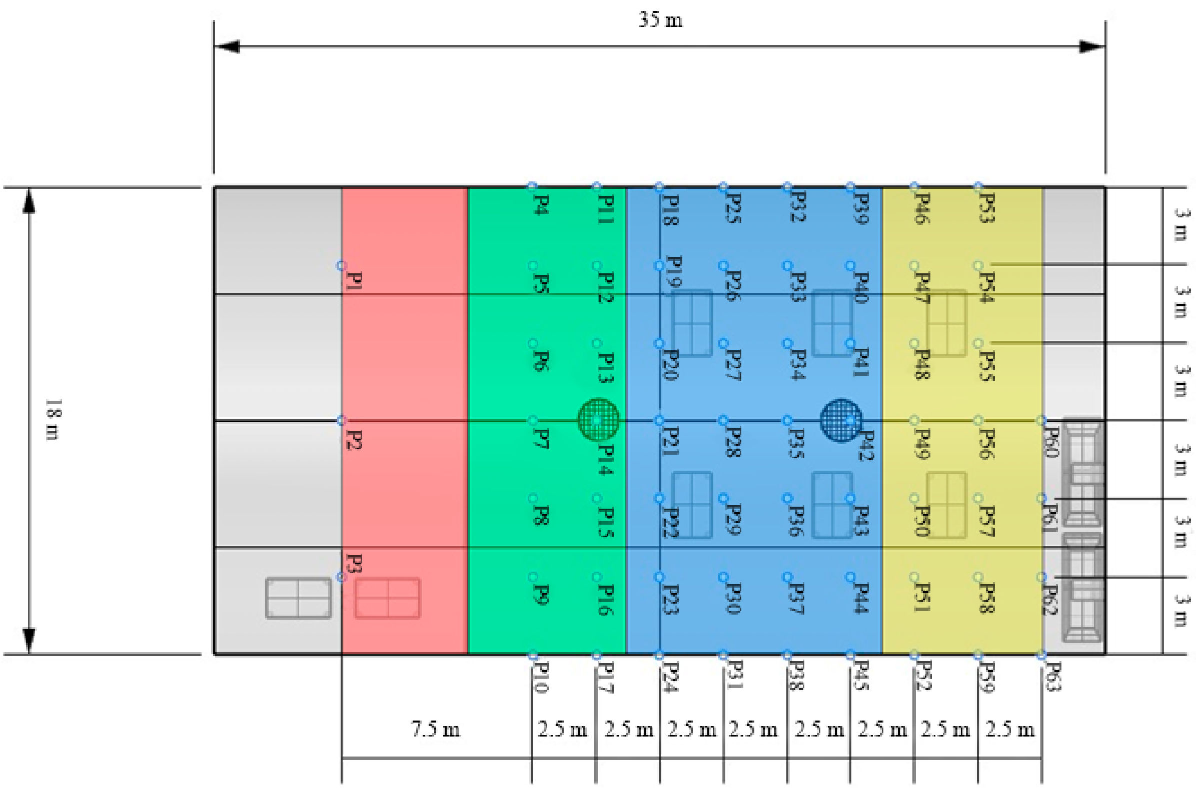
Material and Methods

The study was carried out in Caparrapí, Cundinamarca, Colombia, which is specifically located at the coordinates 5° 20' 39" N, 74° 29' 30" W, with an altitude of 1271 m above sea level.

Non-centrifugal sugar cane production, in industrial quantities in Colombia, has a standardized process, which is described as follows: first, the extracted cane juice is gathered in a tank with a 10000 L capacity. Next, the juice passes through a cleaning process consisting of impurity removal, decantation, and salinity stabilization that lasts 24 hours. Thereafter, production begins with the evaporation procedure to lower the juice moisture level and reach the molding point (FEDEPANELA, 2019).

Once this point is reached, the juice is called honey, and it is poured in the molds, where the drying process takes place through natural convection. Furthermore, the workers take the product out of the molds and check the allowed weight on each one; this process is characterized by the highest noise levels. Finally, during the packaging operation, the product is sealed and stored in boxes.

To conduct the mapping process, data were collected from 63 points distributed throughout the working area (Figure 1), accounting for the distribution of labor within the factory. These points were strategically positioned around key operational zones, including mold tables, evaporators, and packaging sites. These zones were delineated by color-coded



The boxes inside the diagram in the red (packaging area), green (weighing area), blue (molding area), and yellow (evaporation area) areas correspond to the tables used in each one of the production processes

Figure 1. Measurement points inside the factory

areas: red for packaging, blue for weighing, green for molding, and yellow for evaporation. The diagram boxes within each colored area represent the respective production tables. All measurements are expressed in meters (m).

At each designated point, sound levels were measured in dBA using a sound level meter over a two-hour interval. Data collection occurred within a three-hour timeframe: from 7:00 a.m. to 9:00 a.m., 9:00 a.m. to 11:00 a.m., and 11:00 a.m. to 1:00 p.m., which are the shifts in which work is performed each day.

The equipment utilized was configured to measure sound levels in dBA, employing A-weighting as per Ahmed & Gadelmoula (2020), with a PCE-322A sonometer capable of measuring between 30 and 130 dB, with a resolution of 0.1 dB and a precision of 1 dB. The device was programmed to calculate the average level at each point.

The production process is characterized by a cyclical pattern of 120 seconds, with the lowest sound level, followed by a 2-second noise, repeating for two hours, while the workers pull out the non-centrifugal sugar cane from the molds. Then, the procedure continues in the weighing area. Once the non-centrifugal sugar cane is weighed and ready to pack, the process starts over from the molding process. The complete shifts are 10 hours per day (FEDEPANELA, 2019).

For the noise data analysis, during the data analysis process, the normality distribution was checked to verify the validity of the information at each point. Additionally, data were gathered on three different days.

The National Institute for Occupational Safety and Health (NIOSH) establishes that the standard recommendations for exposure limits and calculation procedures dictate a maximum of 85 dB for eight hours per day (NIOSH, 1998). In other words, the daily noise dose, which is the permitted sound level during an eight-hour shift, reaches its limit at 85 dBA (NIOSH, 1998). Following data validation, the daily noise dose (D) was calculated using Eq. 1:

$$D = \left[\frac{C_1}{D_1} + \frac{C_2}{D_2} + \dots + \frac{C_n}{D_n} \right] \tag{1}$$

where:

C_n - the total time of exposure at a specified noise level; and,

D_n - the exposure duration for which noise at this level becomes hazardous (NIOSH, 1998).

Additionally, NIOSH (1998) uses Eq. 2 to calculate the allowed exposure levels (T):

$$T(\min) = \frac{480}{2^{(L-85)/3}} \tag{2}$$

where:

480 - the number of shifts with eight hours;

L - the exposure level, measured in dB; and,

3 - the exchange rate (NIOSH, 1998).

Finally, the time-weighted average (TWA) is the exposure level translated to an eight-hour shift, in case the working system is established differently (NIOSH, 1998); it is calculated as shown in Eq. 3:

$$TWA = 10 \times \log\left(\frac{D}{100}\right) + 85 \tag{3}$$

where:

D - the daily noise dose, calculated with Eq. 1.

Once this was done, a regression technique was applied to determine the best fit to graph the sound level distribution inside the factory using level curves. Maps for the average levels and TWA levels were generated with the help of the software Surfer 21 (Gold Surfer Inc., USA). Here, the root-mean-square error was analyzed to select the model closest to reality.

Results and Discussion

As stated previously, during the production process, workers extract non-centrifugal sugar cane from molds in a cyclical pattern that lasts two hours, featuring a 120-second period of low sound levels followed by a 2-second noise recurrence. Table 1 presents the measured sound levels and corresponding reference durations across three shifts (7:00 a.m. to 9:00 a.m., 9:00 a.m. to 11:00 a.m., and 11:00 a.m. to 1:00 p.m.). The allowed duration was determined for each shift based on the respective sound level; it indicates the maximum number of consecutive hours that workers can remain in the environment at that sound level. It is important to note that as the sound level increases, the permitted duration for workers to be exposed to continuous noise levels decreases, as explained by Bozkurt (2021).

Daily noise doses were computed by considering the exposure duration and predetermined permissible durations. The resultant dose values for each point corroborate the aforementioned notion, indicating that workers are not

Table 1. Sound level and reference duration sample

X	Y	Sound level (dBA)			Allowed duration (h)			D	TWA (dBA)
		7-9 a.m.	9-11 a.m.	11 a.m. - 1 p.m.	T 7-9	T 9-11	T 11-1		
3	0	64.3	68.2	62.0	955.4	388.0	1625.5	0.066	53.2
9	0	58.9	63.5	62.7	3327.0	1149.4	1382.8	0.040	51.0
15	0	67.0	69.4	65.1	512.0	294.1	794.2	0.110	55.4
0	5	63.3	60.8	69.9	1203.8	2144.9	262.0	0.153	56.8
3	5	62.8	62.4	61.6	1351.2	1482.0	1782.9	0.037	50.7
6	5	64.8	62.0	62.1	851.2	1625.5	1588.4	0.044	51.4
9	5	64.8	63.4	63.8	851.2	1176.3	1072.4	0.058	52.6
(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)	(...)

Note - X and Y are coordinates, in meters; D - is the daily noise dose; TWA - is the time-weighted average for an eight-hour shift in dBA subjected to elevated noise levels surpassing the recommended limits. This result is in accordance with previous studies addressing production factories (Susanto et al., 2021).

The time-weighted average was computed using Eq. 3, and it is provided in the last column of Table 1, revealing consistently low noise levels throughout the daily shifts; this aligns with prior findings of elevated noise levels (Ahmed & Gadelmoula, 2020). This analysis also demonstrates an improvement compared to traditional production methods in "trapiches," where sound levels often exceed permitted levels (Quezada-Moreno et al., 2021; González-Campaña & Zúñiga-Cabrera, 2022).

As mentioned previously, the current analysis evaluates the standard conditions for each time gap of two hours. The three time gaps maintain the same sound levels throughout the shifts, presenting variations no higher than 4 dB. The noise levels for the spaces between points were determined by a regression technique for mapping called minimum curvature regression, which is used to determine the behavior of the variability of the study attributes (Crawford et al., 2021).

Figure 2 displays the generated maps illustrating the average sound levels for each time interval. Notably, an increase in sound levels is observed near the walls across all three time intervals. This phenomenon could be attributed to the utilization of

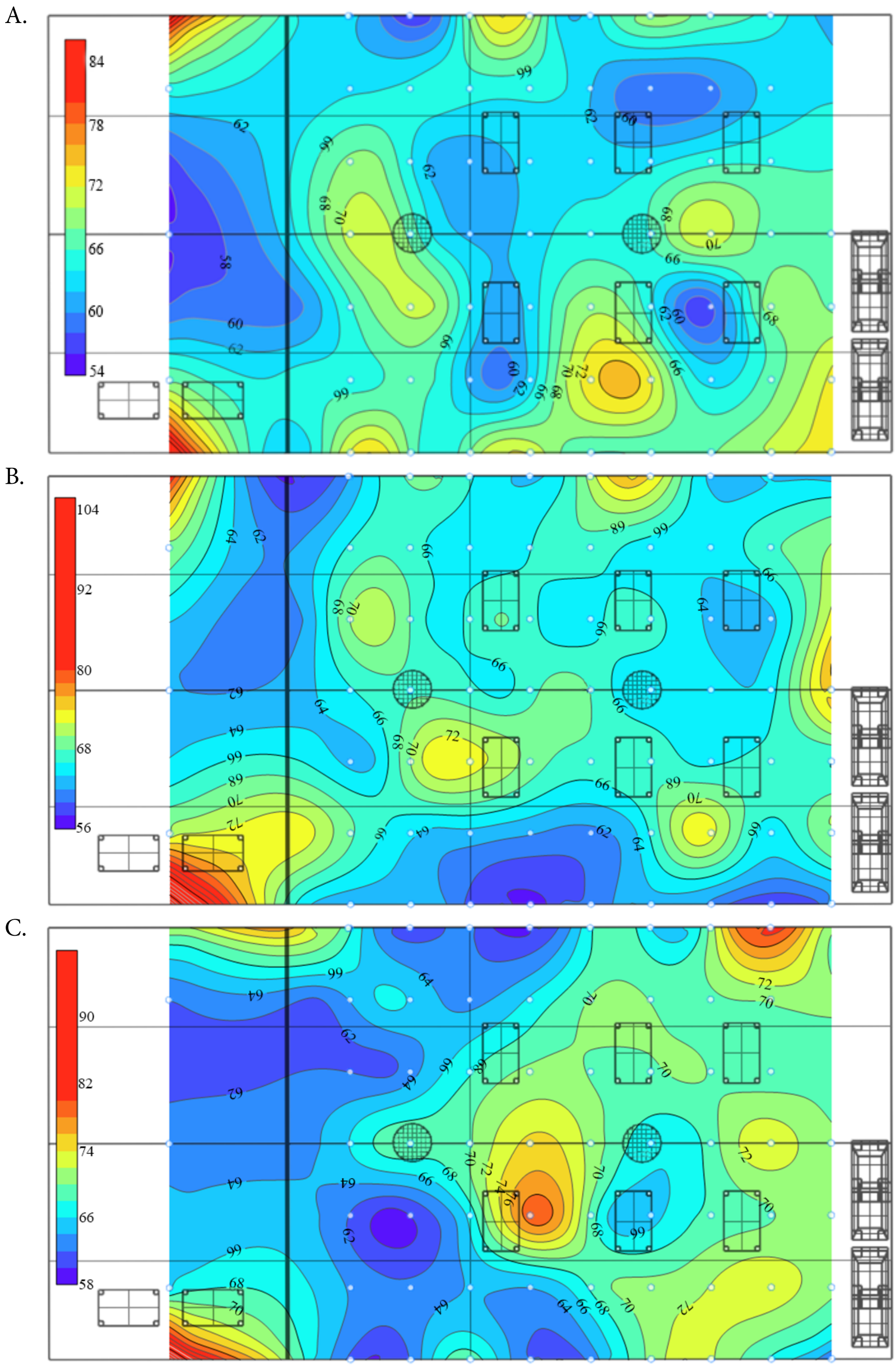


Figure 2. Contour maps of noise during working hours: registered noise levels for shift from 7:00 a.m. to 9:00 a.m. (A), registered noise levels for shift from 9:00 a.m. to 11:00 a.m. (B), and registered noise levels for shift from 11:00 a.m. to 1:00 p.m. (C)

specific tools during the NCS manufacturing process, with the reflected sound from the walls also contributing to the elevated sound levels (Ahmed & Gadelmoula, 2020).

In the packaging area, which is highlighted in red, the noise level is notably elevated due to the constant operation of packaging machinery engines. This elevated noise, compounded by the proximity of the workspace to a wall, can create a reverberating effect, amplifying the overall sound intensity, similar to results presented for black tea processing factories (Çiçek & Sümer, 2021). To address any possible issue effectively, measures such as strategic machinery placement and the use of sound-absorbing materials should be considered to mitigate noise levels and enhance the working environment for employees.

The observation area exhibits consistent similarities across the three time intervals. However, between 7:00 and 11:00 a.m. (as illustrated in Figures 2A and B), the recorded sound levels were notably elevated compared to the readings taken between 11:00 a.m. and 1:00 p.m. (Figure 2C). This discrepancy can be attributed to the performance of the weighing task during the former period, a task typically accompanied by conversations among the workers. These customary interactions often result in sound levels exceeding 70 dB, thereby designating the area as a potential warning zone where permissible noise thresholds may be surpassed.

On the other hand, the molding area presents sound levels that vary. Each time gap shows a different peak zone, which can be attributed to the table change after the completion of the tasks. Additionally, it is important to note that in the proximity of the tables where the workers hear the sound, the levels stay constant, with an average of 65 dB.

In the evaporation area, the average sound levels at the tables reach 67 dB, increasing to around 76 dB near the evaporators due to high-pressure vapor ejection through designated pipes for water evaporation from sugar cane juice. Additionally, during the 11:00 a.m. to 1:00 p.m. timeframe (Figure 2C), a localized increase in sound levels is observed in the upper portion of the map; this is attributed to the practice of opening lateral doors to facilitate airflow due to high temperatures (Ahmed & Gadelmoula, 2020). This results in elevated sound reflection behind the door, with levels exceeding 75 dB, marking another cautionary zone that is nearing the permitted sound limit.

Figure 3 shows the time-weighted average distribution around the factory. These results agree with previous studies, where sound levels increase in close proximity to walls and surfaces (Lim et al., 2018; Ahmed & Gadelmoula, 2020). Additionally, the map reaffirms the previously mentioned warning areas, with the presence of peaks in the molding and evaporation areas.

Moreover, noise levels within the factory remain below the recommended thresholds, as depicted in Figures 2 and 3. This indicates that workers are not experiencing significant stress due to noise levels, thus minimizing potential health impacts (Hernández-Peña et al., 2019). Furthermore, the findings underscore the significance of sound mapping in agro-industrial operations, an area that has previously received limited research attention.

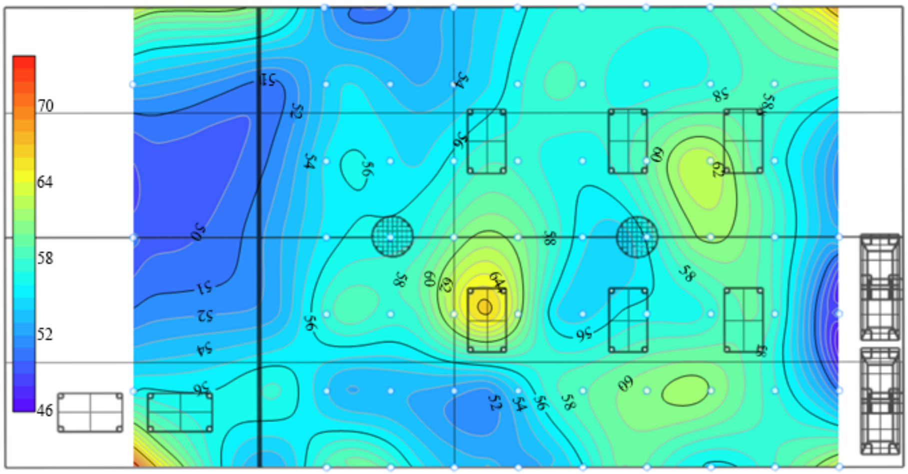


Figure 3. Time-weighted average (TWA) noise level distribution around the factory in dBA

While the sound levels may not surpass hazardous thresholds, it is prudent to take measures to minimize the potential for workplace injuries stemming from elevated noise. Employees can be encouraged to avoid placing themselves near surfaces that amplify sound reflections, as this can contribute to prolonged exposure and potential health issues. Visual cues or warnings should mark these areas as health hazards to prevent the gathering of workers. By being mindful of their positions relative to such surfaces, workers can help maintain a safer and more conducive environment. Additionally, utilizing earmuffs can further safeguard workers against the effects of noise in the workplace, even though the results show that the recommended levels are not exceeded inside the work environment.

Conclusions

1. The overall noise levels generally complied with permissible limits, indicating an acceptable ambient noise level. However, exceptions were noted in areas adjacent to sources of elevated noise activity and reflective walls.

2. High-noise areas should be analyzed using maps to help workers avoid activities with high sound levels. Additionally, the installation of devices like fans, extractors, or refrigeration units inside the factory may increase the measured noise levels.

3. This study shows the potentiality of applying sound mapping to agricultural and agro-industrial production, due to the nature of the activities developed in these kinds of tasks.

4. While the sound levels do not reach hazardous thresholds, to reduce the risk of injuries from workplace noise, workers are advised to avoid being near surfaces that amplify sound reflections.

Contribution of authors: J. D. Alvarez-Carpintero worked on research, data acquisition, data analysis, implementation of the computational simulations, and writing of the manuscript. R. Osorio-Hernández served as a research advisor, contributing to the conceptualization of the problem and refining simulation models through insightful corrections and enhancements. J. H. Camacho-Tamayo advised about the research goals, and contributed in the review and final version of the manuscript.

Supplementary documents: There are no supplementary sources.

Conflict of interest: The authors declare no conflict of interest.

Financing statement: There are not financing statements to declare.

Acknowledgements: Thanks to the Universidad Nacional de Colombia and the professors who helped in this research.

Literature Cited

Ahmed, S. S.; Gadelmoula, A. M. Industrial noise monitoring using noise mapping technique: case study on a concrete block-making factory. International Journal of Environmental Science and Technology, v.19, p.1-12, 2020. https://doi.org/10.1007/s13762-020-02982-9

Alvarez-Carpintero, J.; Osorio-Hernandez, R. Thermal analysis for an unrefined sugar cane processing factory in Colombia by using CFD. In: Proceedings of the European Conference on Agricultural Engineering AgEng. Universidade de Évora, 2021. v.73, p.733-739.

Asikin, Y.; Nakaza, Y.; Maeda, G.; Kaneda, H.; Takara, K.; Wada, K. Evaporation temperature alters physicochemical characteristics and volatile Maillard reaction products of non-centrifugal cane sugar (NCS): Comparison of polyethylene membrane and retronasal aroma simulator techniques for the extraction of volatile organic compounds in NCS. Applied Sciences, v.13, p.1-12, 2023. https://doi.org/10.3390/app13116402

Bozkurt, T. S. Preparation of industrial noise mapping and improvement of environmental quality. Current Pollution Reports, v.7, p.325-343, 2021. https://doi.org/10.1007/s40726-021-00195-3

Crawford, M. M.; Dortch, J. M.; Koch, H. J.; Killen, A. A.; Zhu, J.; Zhu, Y.; Bryson, L. S.; Haneberg, W. C. Using landslide-inventory mapping for a combined bagged-trees and logistic-regression approach to determining landslide susceptibility in eastern Kentucky, USA. Quarterly Journal of Engineering Geology and Hydrogeology, v.54, qjegh2020-177, 2021. https://doi.org/10.1144/qjegh2020-177

Çiçek, G.; Sümer, S. K. Noise exposure levels in black tea processing factories and its effects on employees. Tekirdağ Ziraat Fakültesi Dergisi, v.18, p.282-291, 2021. https://doi.org/10.33462/jotaf.784585

FEDEPANELA - Federación Nacional de Productores de Panela. Protocolo de trazabilidad para obtención de panela. v.1. Bogotá, FEDEPANELA, 2019. 30p.

García, J. M.; Narváez, P. C.; Heredia, F. J.; Orjuela, Á.; Osorio, C. Physicochemical and sensory (aroma and colour) characterisation of a non-centrifugal cane sugar ("panela") beverage. Food Chemistry, v.228, p.7-13, 2017. https://doi.org/10.1016/j.foodchem.2017.01.134

González Campaña, P. J.; Zúñiga-Cabrera, D. C. Impactos ambientales en la producción de panela en la Parroquia de pacto del distrito metropolitano de Quito. Esferas, v.3, p.94-111, 2022. https://doi.org/10.18272/esferas.v3i1.2430

Hasibuan, C.; Sutrisno, F.; Pranatal, B. The instensity measurement and noise mapping in fatty acid plant area at PT. XYZ. Simetrikal Journal of Engineering and Technology, v.2, p.1-8, 2020. https://doi.org/10.32734/jet.v2i1.3556

Hernández-Peña, O.; Hernández-Montero, G.; López-Rodríguez, E. Noise and health. Revista Cubana de Medicina Militar, v.48, p.1-11, 2019.

Jaffé, W. R. Nutritional and functional components of non centrifugal cane sugar: A compilation of the data from the analytical literature. Journal of Food Composition Analysis, v.43, p.194-202, 2015. https://doi.org/10.1016/j.jfca.2015.06.007

Lim, M.; Lee, Y.; Lee, F. W.; Heng, G. Strategic noise mapping prediction for a rubber manufacturing factory in malaysia. E3S Web of Conferences, v.65 , 05019, 2018. https://doi.org/10.1051/e3sconf/20186505019

Mendieta, O.; García. M.; Peña, A.; Rodríguez, J. Las buenas prácticas de manufactura en la producción de panela. 1.ed. Mosquera: Corpoica, 2016. 85p.

Mesías, M.; Delgado-Andrade, C.; Gómez-Narváez, F.; Contreras-Calderón, J.; Morales, F. J. Formation of acrylamide and other heat-induced compounds during panela production. Foods, v.9, 531, 2020. https://doi.org/10.3390/foods9040531

Murphy, E.; Faulkner, J. P.; Douglas, O. Current state-of-the-art and new directions in strategic environmental noise mapping. Current Pollution Reports, v.6, p.54-64, 2020. https://doi.org/10.1007/s40726-020-00141-9

Murphy, E.; King, E. A. Environmental noise pollution: Noise mapping, public health, and policy. 1.ed. Amsterdam: Elsevier, 2022. 267p.

NIOSH - National Institute for Occupational Safety and Health. Occupational noise exposure. 1.ed. Cincinnati: National Institute for Occupational Safety and Health, 1998. 126p.

Polo-Murcia, S. M.; Rodríguez-Borray, G. A.: Cruz-Castiblanco, G. N.; Tauta-Muñoz, J. L.; Huertas-Carranza, B. Rural agro-industrial enterprises diversity: typologies of panela production in Huila, Colombia. Agronomía Mesoamericana, v.33, p.1-23, 2022. https://doi.org/10.15517/am.v33i2.47969

Quezada-Moreno, W. F.; Quezada-Torres, W. D.; Proaño-Molina, M.; Mora-Gutiérrez, M.; Viva-Vivas, M.; Jiménez-Sánchez, A.; González-Suaréz, E.; Molina-Borja, F.; Zambrano-Ochoa, Z. Evaluación del impacto ambiental en el proceso de elaboración de panela mediante el análisis de ciclo de vida. Afinidad, v.78, p.62-67, 2021.

Solís-Fuentes, J. A.; Hernández-Ceja, Y.; Hernández-Medel, M. D. R.; García-Gómez, R. S.; Bernal-González, M.; Mendoza-Pérez, S.; Durán-Domínguez-de-Bazúa, M. D. C. Quality improvement of jaggery, a traditional sweetener, using bagasse activated carbon. Food Bioscience, v.32, p.1-8, 2019. https://doi.org/10.1016/j.fbio.2019.100444

Susanto, A.; Setyawan, D. O.; Setiabudi, F.; Savira, Y. M.; Listiarini, A.; Putro, E. K.; Muhamad, A. F.; Wilmot, J. C.; Zulfakar, D.; Kara, P.; Shofwati, I.; Sodikin, S.; Tejamaya, M. GIS-based mapping of noise from mechanized minerals ore processing industry. Noise Mapping, v.8, p.1-15, 2021. https://doi.org/10.1515/noise-2021-0001

Velásquez, F.; Espitia, J.; Mendieta, O.; Escobar, S.; Rodríguez, J. Non-centrifugal cane sugar processing: A review on recent advances and the influence of process variables on qualities attributes of final products. Journal of Food Engineering, v.255, p.32-40, 2019. https://doi.org/10.1016/j.jfoodeng.2019.03.009