BITLIS EREN UNIVERSITY
JOURNAL OF SCIENCE AND TECHNOLOGY

E-ISSN: 2146-7706

VIBRO-ACOUSTIC ASSESSMENT OF GRAIN GRINDING MACHINE FOR HEALTH RISK FACTORS ANALYSIS

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KEYWORDS

Grain
Grinding machine
Noise
Vibration

ARTICLE INFO

Research Article
DOI: 10.17678/beuscitech.1217010

Received	10 December 2022
Accepted	26 June 2023
Year	2023
Volume	13
Issue	1
Pages	17-37

ABSTRACT

Grinding machines is one of the outcomes of the agricultural sector work process mechanization aimed at reducing tedium and drudgery on the workers and improving overall productivity and production. However, the machinery drive component and mechanical energy are associated with noise and vibration, thereby inducing safety and health concerns for the operators. This study assessed and compared the vibro-acoustic characteristics caused by three different types of grinding machines; electric motor (3HP220V2800HD), diesel (R175A) and petrol (GX160) power drive engines used in grinding shops located in Wadata, Makurdi Local Government Area of Benue State in association with the risk factors to the work environment. The instrumentation design for the grinding machine operations vibro-acoustic characterization was a sound level meter (S844+), a vibrometer (VM-6360), a digital stopwatch (PC-396) and retractable measuring tape (B300-AG). The noise measurements were made at an average seating height of 1.5 m in the operator's work position and the vibrations on the seat surface of the operator. The data obtained were analyzed for noise and vibration occupational risk exposure following the ISO 9612 for acoustics guidelines and ISO 2372 for mechanical vibration and shock. The average mean values for the noise level and vibrations were statistically highest when the diesel power drive engine, followed by the petrol engine, while the electric motor had the least vibro-acoustic effect. In addition, the analysis of the variance test showed that the result obtained for the vibration and noise levels for the three categories of power source drive had p-values less than 0.05, indicating that they are significantly different from zero at a confidence level of 95%. The findings of this study mandated that all operators of the machinery under investigation wear personal protective equipment (PPE).

1 INTRODUCTION

Grinding machine is one of the sustainable developments of agricultural mechanization that has benefited the work process in the field of food processing in operator's efficiency, worktime reduction, facilitation of production activities and increased productivity [1],[2]. The operation of a grain grinding machine for agricultural production processes involves moving of masses, de-backing, breaking and grinding owing to the mechanical drive components such as the driving unit, rollers, damping units, grinding teeth and the engine (which supply mechanical energy). Grinding machines use the principles of abrasion, compression, attrition/shearing, impact or friction forces for size reduction effect in the processing of agricultural raw materials [3]. This operation causes noise and vibrations from the mechanical system of the grinding machine and the work process. In general, mechanical vibrations and noise generation occur in all machinery as long as there are operating. The dynamic forces produced by machinery are often enormous. The widespread use of agricultural machines for work processes has caused some occupational health and safety problems for machine operators [4]-[6].

The vibration from the machine causes whole-body vibration through the floor and the operator's body indirect or direct contact with the grinding machine. The machine and floor vibrate and may harmonize once their frequency approaches each other. However, unwanted vibrations may be induced by large impulsive forces in machines by unbalanced reciprocating of the machine components, gear misalignment and bearing failures [7]. Then again, the vibration may also be due to the grains being fed into the machine and auxiliary equipment [8]. Operators' whole-body vibration is among the most prevalent ergonomic factors affecting agricultural operators' health and work efficiency [9]. According to studies found in the literature, vibrations witnessed in agricultural work processes are a significant health problem causing hazards [10],[11]. Several researchers showed an association between vibration exposure and health issues like musculoskeletal disorders, fatigue, spinal injury, metabolism issues, and cardiovascular and nervous system risks [12]-[15]. Measurement of the vibration will proffer appropriate ways to reduce them at their sources.

Conversely, while assessing the health and safety of employees, in addition to exposure to chemical substances, dust, heat, musculoskeletal disorders, vibration, and noise in agriculture are other significant risk factors that must be considered [9],[16]-[19]. The average limit to noise exposure by the Occupational Safety and Health Administration for a time-weighted average (TWA) of eight hours duration is 86.1 6.2 dBA and 90.2 5.1 dBA for the National Institute of Occupational Safety and Health [20]. The limit of human exposure to vibration as determined by the International Standards Organization (ISO) and accepted by the National Institute of Occupational Safety and Health (NIOSH) and Occupational Safety and Health Administration on daily exposure to whole-body vibration for action is 0.5 m/s^2, with a limit of 1.15 m/s^2 for the frequency-weighted root mean square acceleration. Bilski [21] labelled noise as a significant hazard in the working environment of the agricultural sector. According to studies, noise emissions from farm machinery are not immediately noticeable, but the cumulative impacts over time [22]-[24]. Noise exposure effects on workers include a rise in stress and discomfort levels [25], decreased operational capacity, hampers work efficiency [26], noise-induced hearing loss [9],[27], hampers concentration [26]. mental imbalance, and degenerative physical illnesses [23],[24]. Additional physical impacts of noise exposure include changes in blood pressure, other cardiovascular alterations, higher attendance at general medical practices, issues with the digestive system, and overall weariness [28]-[30]. The noise level at the operator’s ear during his working day is one of the factors that needs evaluation in production systems that use machinery intensively [22]. It is important to note that the noise levels generated by engines vary considerably among mechanical systems of different machines depending on various factors, including the power drive components [21]. Similar studies found in the literature that assessed occupational exposure in food grinding shops considered only noise exposure [31]-[34]. A Google search of different databases found no literature that focused on the noise level and whole-body vibration assessment caused by food grinding machines. As well, none compared the power sources for their effects on the vibration and noise level in the work environment

Measurement of vibration and noise levels aids in indicating and monitoring the performance of the machine and provides an immediate warning whenever the vibration and noise levels rise above the recommended level for the safety and health of the work environment [35]. Most food grinding machine operators are self-employed, and like other entrepreneurs, they control their working hours because they not aware of the relevant occupational health and safety standards, predisposing them to higher risks of noise hazards. This peculiarity sets them apart from workers in other occupations with high noise potentials [36],[37].

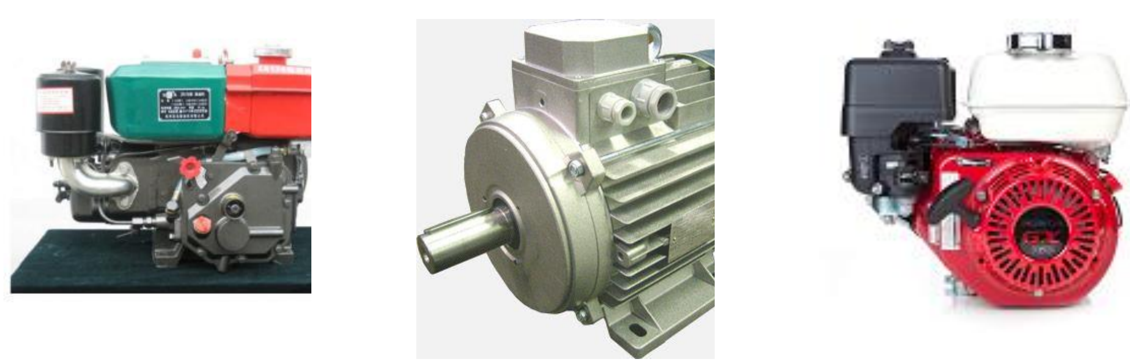
Acoustic engineers objectively characterize vibration and noise exposure in the work environment using noise level meters and vibrometers. The connection between the risk levels due to noise or vibration and stages of health problems is usually determined based on a flexible risk assessment method. The approved guide for the measurements of occupational hazards are found in the international standard organization (ISO 9612 for acoustics severity risk analysis and ISO 2372 for vibration severity risk analysis). The noise and vibration challenges of agricultural work process mechanization in different agricultural sectors has been studied. However, there is no information available that carried out a research on combined noise and vibration challenges of the food grinding machines due to the power drive source and from the standpoint of labour protection. Therefore, this study assessed the operators' occupational whole-body vibration and noise exposure from the power drive sources for the grinding machines used at the grinding shops and interpreted the health severity risk using the established criteria.

2 MATERIALS AND METHODS

The vibro-acoustic characteristics of the grinding machine assessment were conducted on three categories of power drive sources for the grinding machine used in Wadata, Makurdi Local Government Area of Benue State. The study area was considered from the fundamental circumstances obtainable in Nigeria that mechanization of work processes involving agro-based products has reduced the physically strenuous and repetitive activities involved in the food processing operations and the pre-study observation for this study that the grain grinders are frequently overcrowded and as such continuously work each day. They included the following diesel-powered engine (R175A), electric motor (3HP220V2800HD) and petrol-powered engine (GX160) (Figure 1). The specifications of these engines are presented in Table 1 below. The grinding machines had to be in good functioning order, never had a complete breakdown, never had a major part replaced or repaired, be brand new when purchased, and had been purchased within the past 0–2 years were the criteria for the power drive source selected for this study. The vibration effects highlighted by Hoshi [8] such as imbalance, misalignment/shaft run-out, wear and looseness, were taken care of as measures against these faults were checked during the data collection process.

Table 1. *Specifications of the three power drive engines*

Power drive source	Model	Rated power (kw)	Speed (rpm)
Electric motor	3HP220V2800HD	2.23	2800
Diesel powered engine	R175A	4.41	2600
Petrol powered engine	GX160	3.60	3000



Diesel powered engine (R175A) [38]

Electric motor (3HP220V2800HD) [39]

Petrol powered engine (GX160) [40]

Figure 1. *Three categories of power generators for the grinding machines*

The instrumentation design for the data collection in this study were:

A vibrometer - model number VM-6360 (Guangzhou Landtek Instruments CO. Ltd.) was a scientific hand-held measuring device, use to take various assessments of vibrations on machines. It has a frequency range of 10Hz and operates within a temperature range of 0° – 50°.

A sound level meter – model number AS844+ (Neufday Ltd) was an instrument used for acoustic measurement. It is a handheld instrument with a microphone. Its measurement range is between 30 – 130 dB.

A retractable measuring tape - model number B300-AG, was an instrument used to measure distance.

During the evaluation of the physical labor activity, a digital professional (LCD) stopwatch of model PC-396 (Shenzhen super deal Co, Ltd, China) was used to record the duration of the time interval for the job characteristics.

Vibrometer	Sound level meter	Measuring tape	Stopwatch
[41]	[42]	[43]	[44]

Figure 2. *Data collection devices*

This study was limited to the grinding process of the following types of grain; maize, beans, millet, and guinea corn) as they are predominantly ground grains in the locality. These were used to ascertain the associated vibration and noise during the grinding operation. The grains are shown in Figure 3.

Maize

Beans

Millet

Guinea corn

Figure 3. *grains samples*

The grains were ground to smooth textures by grinding each grain twice. The grinding machines were powered by all three power sources—an electric motor, a gasoline engine, and a diesel engine—but different cutting discs were utilized for each operation. The noise and vibration measurements were simultaneously carried out at the unloaded and loaded (the grains grinding operations) stages. The noise level was measured at an average height of about 1.5 meters corresponding to the average ear level of a seated adult [29],[45]. The vibration was determined on the working seat of the machine operator from the grinding machine. The whole-body vibration was measured as it is the vibration transmitted to the entire body via the sit through the mechanical vibrations of the grinding machine affecting the floor and the operators' sits. Whole body vibration was measured using the vibrometer by placing the vibration meter sensor within the seat pad of the operator, which the operator sits on during the grain grinding process. The vibration rhythm of the effect of the grain grinding operation reflects on the dynamic signal analyzer screen for recording. The measurements were taken and recorded five times at intervals of 30 seconds during the idling and the grains grinding operations stages using the power generators, electric motor, petrol and diesel powered engine for the same grinding machine in each case. The average duration of the grinding process recorded for smooth texture (grinding twice) for the three categories of power drive sources varied as 3.5 min/kg, 4.25 min/kg, and 5.5 min/kg for an electric motor and diesel- and petrol-powered engine grinding machines.

The subsequent calculation of the equivalent energy noise level (*LAeq*), which simultaneously incorporates the intensity and exposure time of the environmental noise, is made possible by various noise level measurements during the assessment period. Obtaining a single value that indicates a consistent noise level in the same total sound energy being produced over a certain period, data received in each work duration interval were calculated to an A-weighted equivalent sound pressure level (*LAeq*). The mathematical formula employed for this is as follows:

$$L_{Aeq} = 10\log_{10}\left[\frac{1}{N}\sum_{i=1}^{N}\left(anti\log\frac{L_{Ai}}{10}\right)\right] \quad (1)$$

where

L_{Aeq} = A-weighted equivalent sound pressure level

L_{Ai} = A-weighted sound pressure level in dB

N = total number of measurements

The computed A-weighted equivalent sound pressure level (*LAeq*) at each of the grinding operations shops assessed was analyzed on typical noise levels scale international standard organization. Noise level and vibration were evaluated following the ISO 9612:2009 (acoustics – guidelines for noise exposure assessment in a working environment) and ISO 2372 (mechanical vibration and shock – evaluation of human exposure to whole-body vibration) [35],[46]. The categories of the noise intensity on the typical noise levels scale are presented in tables 2 and 3 below.

Table 2. *Noise level severity risk level criteria [46]*

S/N	Risk level	Noise level severity Criteria (dBA)
I	Tolerable risk	<80
Ii	Justified risk	>80 - 85
Iii	Unjustified risk	>80 - 87
Iv	Inadmissible risk	>87 - 95
V	Intolerable risk	>95

***Table 3**. Vibration severity risk level criteria [35]*

Vibration velocity (mm/s)	Vibration severity criteria
0.28	Good
0.45	
0.71	
1.12	Acceptable
1.80	
2.80	Monitor closely
4.50	
7.10	
11.20	Unacceptable
18.00	
28.00	
45.00	

One-way analysis of variance (ANOVA) was conducted to compare the mean of the noise and vibrations produced during the grain, maize, beans, millet, and guinea corn grinding processes and to determine whether there were significant differences between the groups. These analyses were performed using Microsoft Excel 2016 and the Statistical Package for the Social Sciences (SPSS) 20.0 ($p<0.05$).

3 RESULTS AND DISCUSSION

The descriptive statistics of the vibro-acoustic characteristics of the three categories of power drive sources used in driving the grinding machines were analyzed and presented in table 4. The analysis covered the unloaded and loaded effects of the power drive sources on the seat of the grinding machine operators in the workshops. The result showed that the average mean, standard deviation (SD) and standard error of mean (SEM) of the vibration effect of the diesel-powered source was highest (mean ± SD = 36.02 ± 1.31, SEM = 0.29) mm/s during the unloaded grinding operation of the grinding machine. This was followed by petrol-powered engine (mean ± SD = 20.25 ± 1.26, SEM = 0.28) mm/s and then the electric motor-powered source (mean ± SD = 11.40 ± 0.72, SEM = 0.16) mm/s (Table 4). The vibration values in this study buttressed Jibiri et al. [47] study that the ambient vibrations from a power generating source can be translated to a noticeable vibration effect on the floor and any other thing in contact with it and hence contribute to the noise level. The results of vibration translated from the machine to the seat of the grinding machine operator in the workshop and the noise generated when the machines obtained during the grain grinding process showed that the highest vibration effect was observed when diesel powered engine was the source of driving force for the grinding machines, whereas the electric motor use observed the lowest vibration effect.

Table 4. *Vibration characteristics of the power drive sources assessed*

Characteristic job operations	Power drive sources	Min	Max	Mean ± SD	SEM
Unloaded grinding machine	Electric motor	10.60	13.50	11.40 ± 0.72	0.16
	Petrol powered engine	18.10	22.70	20.25 ± 1.26	0.28
	Diesel powered engine	34.10	39.20	36.02 ± 1.31	0.29
Loaded with Maize	Electric motor	9.00	11.30	10.18 ± 0.66	0.15
	Petrol powered engine	14.30	25.90	21.48 ± 2.35	0.53
	Diesel powered engine	29.90	50.80	35.88 ± 6.13	1.37
Loaded with millet	Electric motor	7.20	10.80	8.55 ± 0.93	0.21
	Petrol powered engine	14.20	22.10	16.56 ± 2.07	0.46
	Diesel powered engine	21.60	35.40	25.95 ± 3.34	0.75
Loaded with guinea corn	Electric motor	7.70	10.10	9.09 ± 0.58	0.13
	Petrol powered engine	12.20	18.60	15.45 ± 1.67	0.37
	Diesel powered engine	21.40	30.40	24.75 ± 2.26	0.50
Loaded with beans	Electric motor	9.60	13.00	11.09 ± 0.79	0.18
	Petrol powered engine	14.50	19.20	16.64 ± 1.26	0.28
	Diesel powered engine	32.00	44.60	38.73 ± 3.86	0.86

Note: Min = Minimum, Max = Maximum, SD = Standard deviation, SEM = Standard error of mean

During the unloaded grinding operation of the grinding machine, the diesel-powered engine source produced the maximum noise level (mean SD = 110.88 2.87, SEM = 0.64), followed by the petrol-powered engine (mean SD = 92.37 2.98, SEM =

0.67). This result followed a similar trend as the vibration. When the electric motor-powered source was engaged, the lowest A-weighted equivalent sound pressure level was recorded throughout the grinding operation of the grinding machine (mean SD = 88.46 3.43, SEM = 0.77) (Table 5). The values obtained in this study buttress the outcome in previous studies found the works of literature that unloaded machines could impose high noise levels in the work environment [29},[48]-[49]. The observation made for the A-weighted equivalent sound pressure level calculated showed that the noise levels generated during the grain grinding process were highest when diesel-powered engines were used to drive the grinding machine. The method of functioning of the petrol and diesel engines can explain the higher A-weighted equivalent sound pressure level calculated from those engines. As reciprocating engines, gasoline and diesel engines generate power through the mechanical motion of their piston-crank systems. Pressure variations caused by the exothermic reaction of hot expanding gases (high temperature and pressure oxidized fuel) in the combustion chamber drive a rotating electric generator for generating driving power. Through the air, motion and vibration generate a series of alternating compression and rarefaction phases. This study agreed with work in the literature that the vibration of the generator frame also affects the surrounding air, which is heard as noise [50].

The survival and achievement of a workplace objective require a healthy workforce, which can only be assured when the environment in which it operates is healthy and safe. Occupational vibro-acoustic characteristic exposure determined by the International Standards Organization has a diverse effect on the occupational health of the exposed workers including noise-induced hearing loss, high blood pressure, heart disease, stress, hand-arm vibration syndrome, fatigue, and loss of balance As such, it is being guided by rules stipulated by the Occupational Safety and Health Administration and NIOSH on the limits to which a worker should be subjected for a particular duration of unsafe and safe usage exposure. Occupational diseases that affect workers that as documented in studies include physical pain, mental agony, and disability which may lead to some deprivation that could continue for the rest of the victim’s life, loss of earning power, loss of leisure activities, extra expenditure for services he can no longer render for himself, loss of family affection and possible loss of life [51],[52]. The health risk factors analysis of the vibration characteristics of the power drive sources assessed through the use of standard typical evaluation criteria zone vibration magnitude (mm/s) when compared to the ISO 2372 for vibration severity risk level criteria for monitoring and machinery protection systems is to ensure the health and continuous operation of the plant machinery revealed 100% unacceptable vibration risk level. This may be due to the portable stand used to fix the power drive source and the grinding unit.

Table 5. *Acoustic characteristics of the power drive sources noise assessed*

Characteristic job operations	Power drive sources	Min	Max	Mean ± SD	SEM
Unloaded machine	Electric motor	83.60	96.90	88.46 ± 3.43	0.77
	Petrol powered engine	86.00	97.90	92.37 ± 2.98	0.67
	Diesel powered engine	104.20	114.70	110.88 ± 2.87	0.64
Loaded with Maize	Electric motor	96.50	104.70	100.58 ± 2.42	0.54
	Petrol powered engine	95.40	103.30	99.20 ± 2.19	0.49
	Diesel powered engine	91.40	99.70	94.34 ± 2.23	0.50
Loaded with millet	Electric motor	85.40	99.90	94.28 ± 4.67	1.04
	Petrol powered engine	89.30	98.90	91.18 ± 2.13	0.48
	Diesel powered engine	92.80	108.10	98.95 ± 4.74	1.06
Loaded with guinea corn	Electric motor	86.90	99.20	95.15 ± 3.48	0.78
	Petrol powered engine	89.80	99.10	91.65 ± 2.10	0.47
	Diesel powered engine	94.70	101.00	98.31 ± 1.91	0.43
Loaded with beans	Electric motor	88.80	94.50	91.42 ± 1.47	0.33
	Petrol powered engine	92.30	104.40	97.33 ± 2.99	0.67
	Diesel powered engine	93.90	101.50	97.51 ± 2.32	0.52

Work operations in a work environment with continuous noise intensity levels are time-bound. The noise level intensity with respect to the recommended noise exposure duration varies, and that determines the level of risk involved. The evaluation of the noise exposure level in this study was done using an 8-hour time-weighted average recommended exposure limit for occupational noise exposure by NIOSH. Monitoring and equipment protection systems, noise level at the grain grinding shops was analyzed and presented in Table 6 to ensure the safety and ongoing functioning of the plant's machinery. The results showed that the noise levels created by the machinery during grinding grain were unjustified risk levels at 58.33% of the examined grain grinding establishments, followed by inadmissible risk levels at 40.63% of the dwellings. The ranges of noise levels obtained were all above the tolerable and justified danger noise levels criteria. The measured noise level analyzed in this study and categorized as an unjustified risk of noise exposure following the international standard organization guidelines for noise exposure assessment in a working environment implies a conscious disregard of a perceived significant risk. The noise level exceeded the workers' tolerance risk capacity; therefore, the grinding shops were unsafe for the workers' bodies. Considering that the NIOSH recommended exposure limit for occupational noise exposure is 85 dBA for an 8-hour time-weighted average, the inadmissible risk (> 87–95 dBA) is an unsafe condition for a workplace as the effect of noise exposure is time-limited [53]. From the results of the vibro-acoustic characteristics of the three types of power drive sources used to drive the grinding machines above, machines generate noise from structure vibration and noise radiation during the cutting processes as a result of the mechanical resonance frequencies of the machine frame and rotating grinding cutter tool. Because there is an industrial regulation protecting workers from noise pollution, it is possible to assess noise pollution and its impact on human health [54]. The recorded values for the three types of power drive sources for the grinding machines evaluated in this study revealed that unloaded when compared with the Nigerian Environmental Standards and Regulation Enforcement Agency's (NESREA) recommended continuous exposure limit of 85 dBA, has noise exposure level potentials for occupational injury in the work environment as the noise level in the three types of power drive sources were higher than 85 dBA. Occupational noise exposure level beyond the maximum permissible noise level for health and safety workers poses a big challenge to the workforce or human resources of any nation as occupational health and safety are interrelated and complementary and, as such, plays an intricate and vital role in the workers' life. This observation was similar to the results obtained by other researchers that assessed the intensity of unloaded machines on the noise level in the work environment [29],[48]-[49].

Table 6*. Categories of the Noise level severity risk at the grinding Shops*

Risk level	Frequency (n)	Percentage (%)
Tolerable risk	0.00	0.00
Justified risk	0.00	0.00
Unjustified risk	280.00	58.33
Inadmissible risk	195.00	40.63
Intolerable risk	5.00	1.04

The analysis of variance (ANOVA) test was performed to examine the effect of power drive sources, such as electric motors, gasoline engines, and diesel engines, on the vibration by comparing the mean square against an estimate of the experimental error. It also emphasized the statistical importance of the effects of each power drive source. The vibration results for the three power drive source categories have p-values less than 0.05 at a 95% confidence level, indicating that they are significantly different from zero (Table 7).

Table 7*. Analysis of variance for the effect of the three power drive sources on noise level*

Characteristics	Representation	Sum of Squares	*df*	Mean Square	*F*-value	*p*-value
Noise	Between Groups	6094.64	2	3047.322	240.239	0.00
	Within Groups	6050.54	477	12.685		
	Total	12145.18	479			

The impact of power drive sources on noise level was examined using a variance analysis, and the statistical F-value for this study was 28.50. The means of the groups are significantly different from each other, since the p-value is less than 0.05 (Table 8). This result indicates that the energy drive sources.

Table 8. Analysis of variance for the effect of the three power drive sources on vibration

Characteristics	Representation	Sum of Squares	*df*	Mean Square	*F*-value	*p*-value
Vibration	Between Groups	34126.79	2	17063.393	1038.28	0.00
	Within Groups	7839.17	477	16.434		
	Total	41965.95	479			

4 CONCLUSION

The operation of a grain grinding machine for agricultural production processes is one of the mechanizations of work operations in food processing industries through the employment of improved tools or equipment to reduce tedium and drudgery on the workers and improve overall productivity and production. This has been found to cause noise pollution in the workplace, which is a health threat to the workers. The vibro-acoustic characteristics of the grinding machine assessment were conducted on three categories of power drive sources for the grinding machine including diesel-powered engine (R175A), electric motor (3HP220V2800HD) and petrol-powered engine (GX160) showed that vibration and noise levels from the grinding machines were high in the three different types of power drive sources considered. The diesel power drive engine produced the loudest noises and the most tremors, followed by the gasoline engine and the electric motor. The result for the vibration and noise levels for the three categories of power source drive had p-values less than 0.05, showing that they are substantially different from zero at a 95% confidence level, according to the analysis of the variance test. Analysis of the whole-body vibration and the noise exposure of the operators using the established vibration and noise exposure standard for limit in the work environment showed that the whole-body vibration and the noise emission levels of the operators in the grinding shops are unsafe for human health, which was a risk concern According to this study's results, personal protective equipment is recommended for the workers in the grinding shops, irrespective of the categories of power drive sources for the grinding machine.

Conflict of interest

There is no conflict of interest between the authors.

Authors contributions

Conceptualization and the design of the framework was carried out by Amine D.J; Azodo A.P identified the gap in the literature that the work intended to bridge, drafted and revised the manuscript; data collection and analysis was handled by Owhor S.C. the three authors were substantively involved in the manuscript proofreading.

Research and Publication Ethics

This study was approved by ethics and research committee of Federal University of Agriculture, Makurdi with approval code 15/32933/UE, March, 2021.

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