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Characterization of the physical properties and risks associated with soybean and soybean meal dusts

Caracterização das propriedades físicas e dos riscos associados às poeiras de soja e farelo de soja

Caracterización de las propiedades físicas y de los riesgos asociados al polvo de soja y harina de soja

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Abstract: Dust generation during the storage of agricultural products can pose risks to worker health and the safety of storage facilities. Thus, this study aimed to physically characterize soybean dust and soybean meal dust to identify potential occupational and explosion risks associated with their properties. Samples of soybean dust (collected in Ijaci, MG) and soybean meal dust (collected in Paranaguá, PR) were analyzed for moisture content, particle size distribution, and Gross Calorific Value (GCV). The results showed that soybean meal dust exhibited a higher GCV (19.48 MJ kg^{-1}) and higher moisture content (12.91% w.b.) compared to soybean dust (16.98 MJ kg^{-1} and 10.98% w.b., respectively), as well as a finer particle size distribution (D50 of 171.38 µm versus 518.22 µm). The fraction smaller than 100 µm accounted for approximately 1% of the mass of both dust types and warrants attention regarding occupational exposure due to the smaller particle size and the potential for penetration into the respiratory tract. The observed particle size characteristics and GCV indicate potential risks associated with occupational exposure and the combustibility of these dusts.

Keywords: Particle size distribution. Calorific value. Moisture content. Combustibility. Occupational exposure.

Resumo: A geração de poeiras durante o armazenamento de produtos agrícolas pode representar riscos à saúde dos trabalhadores e à segurança das unidades armazenadoras. Assim, este estudo teve como objetivo caracterizar fisicamente as poeiras de soja e farelo de soja, visando identificar possíveis riscos ocupacionais e de explosão associados às suas características. Foram analisadas amostras de poeira de soja, coletadas em Ijaci–MG, e de farelo de soja, coletadas em Paranaguá–PR, quanto ao teor de água, à granulometria e ao Poder Calorífico Superior (PCS). Os resultados mostraram que a poeira de farelo de soja apresentou maior PCS (19,48 MJ kg^{-1}) e maior teor de água (12,91% b.u.) em comparação à poeira de soja (16,98 MJ kg^{-1} e 10,98% b.u., respectivamente), além de distribuição granulométrica mais fina (D50 de 171,38 µm contra 518,22 µm). A fração inferior a 100 µm representou aproximadamente 1% da massa de ambas as poeiras e merece atenção quanto à exposição ocupacional, devido ao menor tamanho das partículas e à possibilidade de penetração no trato respiratório. As características granulométricas e o PCS observados indicam possíveis riscos associados à exposição ocupacional e à combustibilidade dessas poeiras.

Palavras-chave: Granulometria. Poder calorífico. Teor de água. Combustibilidade. Exposição ocupacional.

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Resumen: La generación de polvo durante el almacenamiento de productos agrícolas puede representar riesgos para la salud de los trabajadores y la seguridad de las instalaciones de almacenamiento. Este estudio tuvo como objetivo caracterizar físicamente el polvo de soja y de harina de soja para identificar posibles riesgos ocupacionales y de explosión asociados a sus características. Se analizaron muestras de polvo de soja, recogidas en Ijaci–MG, y de harina de soja, recogidas en Paranaguá–PR, en cuanto al contenido de humedad, la granulometría y el poder calorífico superior (PCS). Los resultados mostraron que el polvo de harina de soja presentó mayor PCS (19,48 MJ kg^{-1}) y mayor contenido de humedad (12,91% b.h.) que el polvo de soja (16,98 MJ kg^{-1} y 10,98% b.h., respectivamente), además de una distribución granulométrica más fina (D50 de 171,38 µm frente a 518,22 µm). La fracción inferior a 100 µm representó aproximadamente el 1% de la masa de ambos tipos de polvo y merece atención en relación con la exposición ocupacional, debido al menor tamaño de las partículas y la posibilidad de penetración en el tracto respiratorio. Las características granulométricas y el PCS observados indican posibles riesgos asociados a la exposición ocupacional y la combustibilidad de estos tipos de polvo.

Palabras clave: Granulometría. Poder calorífico. Contenido de humedad. Combustibilidad. Exposición ocupacional.

1. Introduction

Brazil occupies a prominent position in the production and export of soybeans worldwide, playing an important role in agribusiness. In the 2025/26 harvest, the national production reached the record of 180.4 million tons, the largest volume recorded in the historical series of the National Supply Company. For the same period, oilseed exports were estimated at 116.1 million tons (CONAB, 2026).

This growth in national production increases the demand for infrastructure for storage and processing of grains and their by-products, among which stands out soybean meal, widely used as a protein source in animal feed (THIAGO; SILVA, 2003).

The postharvest stage of soybean comprises essential operations, such as drying, processing, transport and storage, intended to preserve the quality of the grains until their commercialization or processing (SOUZA et al., 2023). During these operations, especially in the steps of movement and storage, the generation of particulate matter occurs due to the friction between the grains and the detachment of particles during handling (ANDRADE; BORÉM, 2004).

The dust generated during processing and movement of grains and their by-products can represent risks to workers' health and the safety of facilities (PEIXOTO; FERREIRA, 2012). From the occupational point of view, exposure to these particles may be associated with adverse effects on the respiratory system, including respiratory diseases and allergic reactions. For the purpose of evaluating occupational exposure, particles are classified into inhalable, thoracic

and respirable fractions, according to specific conventions related to their behavior in the respiratory tract (FUNDACENTRO, 2009).

Hansen et al. (2023), Eriksen et al. (2023) and Madsen et al. (2024) demonstrated that, in environments of organic waste management, the inhalable fraction of particulate matter can transport bacteria and fungi, favoring its deposition in different regions of the respiratory tract. The presence of endotoxins in inhalable dust was also documented, with concentrations that may exceed suggested occupational limits (Hansen et al., 2023).

Particles with diameter less than 100 μm may remain suspended in the air for prolonged periods, increasing the exposure time of workers (ANDRADE; BORÉM, 2004). In addition to the effects on health, the presence of suspended dust may represent a risk of fire and explosion. According to OSHA (1997), dust is among the main causes of industrial explosions, especially grain dust in this context.

When aerodispersoids remain suspended in the air at adequate concentrations and come into contact with an ignition source, the formation of an explosive atmosphere can occur, capable of triggering fires and explosions (SA, 2007). Santamaria-Herrera et al. (2023) demonstrated that particles with smaller particle size, due to their greater relationship between surface area and mass, can favor ignition and flame propagation. The authors observed explosive behavior in moisture contents of approximately 30% for particles smaller than 125 μm, while for particles between 125 and 250 μm, this behavior was observed up to approximately 14% of moisture content. Thus, smaller particles may present greater susceptibility to ignition and combustion propagation under certain conditions.

In storage units, the generation and accumulation of dust during handling and processing operations, associated with the presence of possible ignition sources, such as electrical installations, metallic surfaces and bearings subjected to excessive friction, can favor the occurrence of fires and explosions. During these operations, it is estimated that between 0.1% and 1% of the volume of processed grains will be converted into particulate matter (ANDRADE; BORÉM, 2004).

Despite the available information on the risks associated with dust of agricultural products in storage units (SÁ, 2007; PEIXOTO; FERREIRA, 2012; SALIBA, 2016), investigations are still needed on the characteristics of soybean dust and soybean meal generated under real storage conditions in Brazil, especially regarding the properties related to occupational exposure and the combustibility of these materials.

The objective of this study was to physically characterize the soybean and soybean meal dust generated in storage units, as well as to evaluate the potential occupational and explosion risks associated with these materials in the workplace.

2 Theoretical framework

2.1. Agroindustrial processing and particulate matter generation

During the movement and processing of agricultural products, friction and mechanical impacts can promote grain fragmentation and particle detachment, contributing to dust generation (KHAN et al., 2022). The moisture content of the product also influences this process, since the reduction of moisture can increase the fragility of grains and favor the formation of particles during handling (SALETNIK et al., 2021). The generation of particulate matter during these operations can result in high concentrations of dust in the vicinity of equipment such as grinds and dryers, making it necessary to control air quality to reduce occupational exposure and minimize risks to facilities (HALSTENSEN et al., 2007).

The generated particles can remain dispersed in the air, characterized as aerodispersoids, whose behavior is influenced by factors such as size, density, shape of particles and ventilation conditions of the environment (HUESCAR MEDINA et al., 2015). Smaller particles have higher capacity to remain suspended and can be transported by air currents for prolonged periods (FUMAGALLI et al., 2016). With the reduction of air velocity, part of this material can be deposited on machines, structures and platforms, forming layers of combustible dust (BU et al., 2019). The resuspension of this deposited material, caused by vibrations or other disturbances, can contribute to the formation of atmospheres with enough dust concentration to favor the occurrence of secondary explosions (JOSEPH, 2007).

The characterization of particulate matter is important for the understanding of its dynamics in the workplace and for the establishment of control measures. Active sampling methods can be used to determine the concentration of suspended particles, using aspiration systems associated with appropriate filters (DOUWES et al., 2003). Gravimetric determination allows quantifying the mass of particulate matter collected, while techniques such as Scanning Electron Microscopy (SEM) can provide information on particle morphology and size (BOATMAN et al., 1988). This information can support the selection and sizing of control measures, such as local exhaust ventilation systems and mango filters, contributing to the reduction of occupational exposure and dust accumulation in facilities (KHAN et al., 2022).

2.2. Physical properties: Granulometric distribution, humidity and dust behavior

The particle size distribution is an important characteristic of the dust generated during agroindustrial operations, since the particle size influences its behavior in the environment and its interaction with combustion processes. The reduction of particle size increases the relationship between surface area and mass, favoring contact with oxygen and may facilitate heat transfer and release of volatile components during combustion (HUESCAR MEDINA et al., 2015; FUMAGALLI et al., 2016). Thus, smaller particles may present higher susceptibility to ignition and combustion propagation, although the behavior of dust in fire or explosion situations also depends on factors such as composition, concentration of particles in the air, moisture content and presence of ignition source (REDING; SHIFLETT, 2018; KHAN et al., 2022).

In addition to influencing the behavior during combustion, particle size interferes with the permanence of suspended particles in the environment. Smaller particles have greater ability to remain dispersed and be transported by air currents, while larger particles tend to sediment more quickly (HALSTENSEN et al., 2007). Part of the particulate matter can therefore be deposited on machines, platforms, beams and other surfaces of agroindustrial installations, forming layers of combustible dust (BU et al., 2019). The resuspension of this deposited material, caused by vibrations, movement of equipment or other disturbances, can increase the concentration of dust in the air and contribute to the occurrence of secondary explosions when favorable ignition conditions are present (JOSEPH, 2007).

Granulometry also has importance for the evaluation of occupational exposure. The behavior of particles in the respiratory system is related to their aerodynamic characteristics, being used, for occupational hygiene purposes, the conventions of inhalable, thoracic and respirable fractions. Particles belonging to smaller fractions can reach deeper regions of the respiratory tract, increasing the possibility of pulmonary deposition and adverse health effects, depending on the composition and concentration of inhaled material (DOUWES et al., 2000; DUOWES et al., 2003; HALSTENSEN et al., 2007). Thus, the granulometric characterization of dust constitutes a relevant information both for understanding its behavior in the environment and for evaluating the exposure of workers.

The moisture content also influences the behavior of dust during combustion. The presence of water can absorb part of the thermal energy supplied to the system during ignition, since the evaporation of water requires energy, contributing to the reduction of the temperature

available for combustion (KUAI et al., 2011; MITTAL, 2013). Consequently, the increase in moisture content can reduce ignition ease and modify the intensity of combustion, although this effect depends on the characteristics of the material and the conditions under which ignition occurs (SALETNIK et al., 2021).

Thus, both particle size distribution and moisture content are relevant properties for the characterization of agricultural dust. Smaller particles tend to have higher relative surface area and greater ability to remain in suspension, while increasing moisture content can reduce its susceptibility to ignition. The joint evaluation of these properties allows a better understanding of the behavior of soybean dust and soybean meal and its possible implications for occupational exposure and safety of storage units.

2.3. Energy characterization and fuel behavior of dust

The energy potential of organic dust can be characterized by the Gross Calorific Value (GCV), a parameter that represents the amount of energy released during the complete combustion of the material, also considering the energy associated with the condensation of water vapor formed during the process (SALETNIK et al., 2021). When grain residues are subjected to intense drying processes or heat treatments, changes in their composition and structure may occur, with a reduction in moisture content and certain volatile compounds and consequent relative increase in the fixed carbon fraction (HUESCAR MEDINA et al., 2015).

According to Saletnik et al. (2021), thermal treatments applied to biomass can increase its available energy by up to 62%, modifying its behavior during combustion. In confined environments, these changes may contribute to more favorable conditions for the propagation of dust combustion dispersed in the air. Even in its untreated state, agricultural dust has relevant energy content, especially when subjected to conditions that favor ignition and combustion (REIS et al., 2012).

The moisture content is another important factor in the behavior of dust during combustion. The water present in the particles absorbs part of the thermal energy supplied to the system to promote its evaporation, reducing the energy initially available for heating and ignition of the fuel material (MITTAL, 2013). Thus, the increase in moisture content can hinder ignition and reduce combustion intensity, although this effect depends on dust characteristics and conditions of dispersion and ignition. Thus, moisture acts as a factor capable of modifying the behavior of dust during combustion processes, without, however, eliminating necessarily the risk associated with the presence of particulate fuel.

In agroindustrial units, the continuous accumulation of dust on machines, beams, platforms and other surfaces can increase the availability of fuel material in the environment and contribute to the occurrence and spread of fires and explosions (JOSEPH, 2007). During an explosion, the high concentration of suspended particles can change combustion conditions and favor the formation of partially burned products, some of which may be deposited on the surfaces of the installations (BU et al., 2019). These heated or incandescent materials can act as secondary sources of ignition and contribute to the occurrence of fires in deposited dust layers, known as layer fire.

Surfaces of equipment that reach high temperatures, resulting from friction, overheating or other operating conditions, can also constitute hotspots capable of starting the combustion of deposited dust (BU et al., 2019). Once the combustion of a dust layer has begun, the released heat can favor the ignition of nearby combustible materials and, if the deposited dust is again dispersed in the environment, contribute to the formation of a new combustible dust cloud. This process can favor the occurrence of secondary explosions, whose intensity can be influenced by the amount of dust available, dispersion conditions, confinement and the presence of ignition sources (JOSEPH, 2007; BU et al., 2019).

The possibility of propagation of combustion in dust layers is also related to the thickness and characteristics of the deposit. Thinner layers have greater ease of heat dissipation for adjacent surfaces, while thicker deposits can favor heat retention and continuity of the combustion process (BU et al., 2019). Thus, the accumulation of combustible dust should be considered an important safety factor in storage and processing facilities for agricultural products, especially when associated with potential ignition sources and the possibility of resuspension of particulate material.

2.material and method

The present work was developed at the Department of Agricultural Engineering of the Federal University of Lavras (UFLA), in Lavras, Minas Gerais. The analyzed material consisted of soybean dust and soybean meal, collected in storage units located in Ijaci-MG and Paranaguá-PR, respectively.

Sample collection was performed later to identify the deposition points of suspended particulate matter in the environment. The sampling was carried out at points located more than 1.5 m high in relation to the floor, seeking to obtain material deposited in regions corresponding to the height of exposure of workers (FUNDACENTRO, 2009).

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The moisture content of the dust was determined by the greenhouse method, adapted from the Rules for Seed Analysis, at a temperature of 105 ± 3 °C, for 24 h (BRASIL, 2009). For each determination, approximately 25 g of sample were used, with three repetitions.

The particle size distribution of the dust was determined using a Lucadema sieve vibrator, by separating the particles according to the size of the sieves openings. The test was carried out in two replications, using approximately 200 g of sample in each repetition, deposited on the sieve with greater opening. The set of sieves was subjected to vibration at maximum intensity (level 10), for 15 minutes.

The sieving set consisted of eight sieves, with openings of 2,000, 1.400, 850, 180, 150, 106, 90 and 75 µm. Under the last sieve was placed a collector container, called "bottom" for the retention of particles with size less than 75 µm. After sieving, each sieve and the collector container were weighed, allowing to determine the mass of retained material in each particle size class and its respective proportion in relation to the total sample mass.

The Gross Calorific Value (GCV) was determined using a calorimetric pump IKA, model C200. Initially, the samples were subjected to oven drying at 105 ± 3 °C for 24 h. After drying, approximately 0.25 g of each sample were weighed and packed in the crucible of the calorimetric pump. Then, the container was pressurized with oxygen and subjected to combustion, being determined the energy released during the burning of the sample.

3. Results and discussion

The gross calorific values (GCV) differed significantly between the evaluated materials. Soybean meal dust presented GCV of 19.48 MJ kg^{-1}, higher than that observed for soybean dust (16.98 MJ kg^{-1}), indicating higher energy content per unit of mass for soybean meal dust under the conditions in which the samples were evaluated. The results of the GCV analysis, particle size fraction less than 100 µm, mean diameter D50 and moisture content are presented in Table 1.

Table 1. Higher calorific value (GCV), particle size fraction less than 100 µm, mean diameter D50 and moisture content of soybean and soybean meal dust.

Analyses	Dust	
	Soybean meal	Soybean
GCV (MJ.kg^{-1})	19.48 a	16.98 b
Particle size (< 100 µm)	1.1 a	1.0 a
Moisture content (% w.b.)	12.91 a	10.98 b
Mean diameter D50 (µm)	171,38	518,22

Equal letters in the same line indicate that there is no statistically significant difference by Tukey's test at 5%.

The difference observed in GCV may be related to the chemical composition of materials. Soybean meal is constituted by an organic fraction from the processing of grains, and may present different proportions of proteins, lipids, carbohydrates and other compounds in relation to dust originated directly from soybean grains. Xu, Xu and Liu (2024) highlight the contribution of organic constituents of bran to their energy characteristics. Thus, differences in the composition of organic matter can contribute to the higher GCV observed in soybean meal dust.

The moisture content also differed significantly between the materials, being 12.91% for soybean meal dust and 10.98% for soybean dust. As water does not contribute to the release of energy during combustion and still absorbs energy in the form of sensitive and latent heat, higher levels of water tend to reduce the calorific value when it is expressed on a wet basis. Therefore, the highest GCV observed for soybean meal dust, even with higher moisture content, reinforces the possibility of differences in the composition of the fuel fraction between the materials.

The values obtained are in the range observed for other biomasses. Huéscar Medina et al. (2015) reported GCV of 21.2 MJ kg^{-1} for Norway spruce and 20.8 MJ kg^{-1} for Southern pine, values close, although higher, to that obtained for soybean meal dust. Saletnik et al. (2021), in turn, observed GCV of approximately 17.34 MJ kg^{-1} for unprocessed biomass of apple, a value close to that observed for soybean dust. These differences highlight the influence of the composition and characteristics of the raw material on the energy content of biomasses.

The granulometric distribution of the samples showed differences between the materials (Figure 1). Soybean dust concentrated approximately 64% of its mass in the fraction of 180 µm, while soybean meal dust showed higher retention in the fraction of 150 µm, corresponding to approximately 50% of the mass. It was observed, therefore, a dislocated distribution to smaller diameters in soybean meal dust, indicating greater relative participation of smaller particles in this material.

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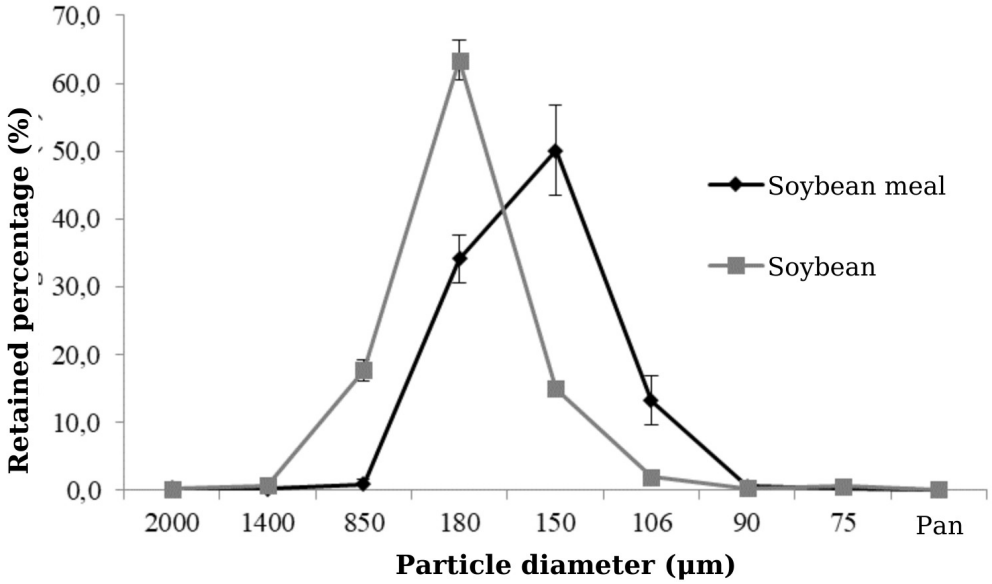
Figure 1. Granulometric distribution of soybean meal and soybean dust.



This difference is also evidenced by the mean diameter corresponding to 50% of the distribution (D50). Soybean bran dust presented D50 of 171.38 µm, while soybean dust presented 518.22 µm. Therefore, half of the particle size distribution of soybean meal dust is in particles smaller than approximately 171 µm, while for soybean dust, this value was approximately 518 µm.

The value obtained for soybean meal dust was higher than that reported by Xu, Xu and Liu (2024), which found D50 of 23,197 µm. This difference may be related to the way of obtaining the samples. In the present study, dust was collected directly from the processing environment, while Xu, Xu and Liu (2024) used soybean meal submitted to milling. The grinding process tends to produce smaller particles, which may explain part of the observed difference between studies. For woody biomasses, Huéscar Medina et al. (2015) reported D50 of 712 and 722 µm for Norway spruce and Southern pine, respectively, while Saletnik et al. (2021) found D50 between 73.5 and 86.365 µm for biochars from branches of fruit trees. These comparisons demonstrate that the granulometric distribution is influenced by the origin of the raw material and, mainly, by processing operations, generation, collection and preparation of samples.

The fraction of particles with diameter less than 100 µm represented 1.1% of the dust mass of soybean meal and 1.0% of soybean dust, and no statistical difference was observed between the materials. Despite the small mass proportion, this fraction is relevant from the perspective of occupational health, since smaller particles have greater potential to remain suspended in the air and reach deeper regions of the respiratory tract, depending on their aerodynamic characteristics and exposure conditions.

In the context of organic dust, the fine fraction can act as a vehicle for microorganisms and biologically active components, such as endotoxins and β-glucans. Douwes et al. (2003) and Halstensen et al. (2007) associated occupational exposure to organic dust with inflammatory responses and respiratory changes. Douwes et al. (2000), in turn, observed changes in inflammatory markers in workers exposed to bioaerosols, evidencing that relatively small fractions by mass may present biological relevance. Thus, although the fraction less than 100 μm represents approximately 1% of the total dust mass evaluated, its presence should be considered in occupational exposure control strategies in processing environments.

The granulometric characteristics, GCV and moisture content are also relevant for the evaluation of combustible dust behavior. The highest GCV observed for soybean meal dust indicates higher energy content per unit of mass, while the lowest D50 shows greater relative participation of smaller particles. Smaller particles have higher specific surface area and can favor heat transfer, heating and combustion processes when dispersed in the air. Huéscar Medina et al. (2015) demonstrated that the reduction of particle size may favor the reactivity of combustible dust due to changes in heat and mass transfer mechanisms and greater availability of fuel components.

Fumagalli et al. (2016) also discussed the influence of particle size on explosivity, highlighting that, for small enough particles, the influence of additional size reduction may become less pronounced. Thus, although the fraction less than 100 μm presents characteristics that may favor its participation in ignition and flame propagation processes, its low mass participation does not allow to affirm, in isolation, that it is responsible for the occurrence or severity of an eventual explosion. The behavior of the dust cloud also depends on the concentration of particles in the air, ignition energy, oxygen availability, moisture content and other properties of the material.

The moisture content can also modify the behavior of a dust cloud. Soybean meal dust presented significantly higher moisture content (12.91%) than soybean dust (10.98%). The increase in moisture can influence the dispersion and agglomeration of particles, besides interfering with combustion processes. Mittal (2013), when evaluating coal dust, observed influence of moisture content on the Limit Oxygen Concentration (LOC), while Addai et al. (2016) discussed the influence of moisture on mechanisms related to dispersion and behavior of combustible dust. Although these studies have been carried out with other materials, they show that moisture should be considered in the interpretation of dust behavior.

Together, soybean meal dust showed higher GCV (19.48 MJ kg^{-1}), lower D50 (171.38 μm) and higher moisture content (12.91%), compared to soybean dust, which presented 16.98

MJ kg^{-1}, 518.22 μm and 10.98%, respectively. These results show relevant differences between the materials regarding their energy, particle size and moisture characteristics. However, the determination of explosivity requires specific tests, such as maximum explosion pressure (Pmax), maximum pressure increase rate (Kst), minimum explosive concentration (MEC), minimum ignition energy (MIE) and oxygen limit concentration (LOC).

Thus, the results obtained constitute a preliminary characterization of the properties that can influence the behavior of dust and provide subsidies for the assessment of the risks associated with the storage, transport and processing of these materials, but do not allow, alone, quantify or classify the severity of an eventual explosion.

Final considerations

Soybean and soybean meal dust showed differences in calorific value, moisture content and granulometric distribution. Soybean meal dust presented higher GCV (19.48 MJ kg^{-1}), higher moisture content (12.91% w.b.) and lower D50 (171.38 μm) compared to soybean dust (16.98 MJ kg^{-1}; 10.98% w.b.; 518.22 μm). The fraction less than 100 μm corresponded to approximately 1% of the mass of both dusts, showing relevance for occupational exposure and combustible dust behavior. These results reinforce the need for control measures during the handling and processing of these materials, although the characterization of the explosivity requires specific tests.

References

ADDAI, E. K.; GABEL, D.; KRAUSE, U. Experimental investigations of the minimum ignition energy and the minimum ignition temperature of inert and combustible dust cloud mixtures. Journal of Hazardous Materials, v. 307, p. 302–311, 2016.

ADEBIYI, A. A.; KOK, J. F. Climate models miss most of the coarse dust in the atmosphere. Science Advances, v. 6, n. 15, eaaz9507, 2020.

ADEBIYI, A. A.; KOK, J. F.; MURRAY, B. J.; RYDER, C. L.; STUUT, J.-B. W.; KAHN, R. A.; KNIPPERTZ, P.; FORMENTI, P.; MAHOWALD, N. M.; PEREZ GARCIA-PANDO, C.; KLOSE, M.; ANSMANN, A.; SAMSET, B. H.; ITO, A.; BALKANSKI, Y.; DI BIAGIO, C.; ROMANIAS, M. N.; HUANG, Y.; MENG, J. A review of coarse mineral dust in the Earth system. Aeolian Research, v. 60, 100849, 2023.

AMERICAN SOCIETY FOR TESTING AND MATERIALS. E711-87: Standard Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter. Philadelphia: ASTM International, 2004. 8 p.

AMYOTTE, P. R.; MINTZ, K. J.; PEGG, M. J.; SUN, Y.-H.; WILKIE, K. I. Laboratory investigation of the dust explosibility characteristics of three Nova Scotia coals. Journal of Loss Prevention in the Process Industries, v. 4, n. 2, p. 102–109, 1991.

ANDRADE, E. T.; BORÉM, F. M. A safra pelos ares. Revista Cultivar Máquinas, ed. 28, 2004. Available at: http://www.grupocultivar.com.br/arquivos/m28_acidentes.pdf. Accessed on: 20 set. 2026.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 8633: carvão vegetal: determinação do poder calorífico. Rio de Janeiro: ABNT, 1984. 13 p.

ASTM. D5865-03: Standard test method for gross calorific value of coal and coke. In: Annual book of ASTM standards. West Conshohocken: American Society for Testing and Materials, 2003.

BOATMAN, E. S.; COVERT, D.; KALMAN, D.; LUCHTEL, D.; OMENN, G. S. Physical, morphological, and chemical studies of dusts derived from the machining of composite-epoxy materials. Environmental Research, v. 45, n. 2, p. 242–255, 1988.

BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. Regras para análise de sementes. Brasília: Mapa/ACS, 2009.

BU, Y.; YUAN, C.; AMYOTTE, P.; LI, C.; CAI, J.; LI, G. Ignition hazard of non-metallic dust clouds exposed to hotspots versus electrical sparks. Journal of Hazardous Materials, v. 365, p. 895–904, 2019.

COMPANHIA NACIONAL DE ABASTECIMENTO. Conab estima produção de 361,7 milhões de toneladas de grãos na safra 2025/26. Brasília: Conab, 2026. Available at: https://www.gov.br/conab/pt-br/assuntos/noticias/conab-estima-producao-de-361-7-milhoes-de-toneladas-de-graos-na-safra-2025-26. Accessed on: 20 set. 2026.

DOUWES, J.; THORNE, P.; PEARCE, N.; HEEDERIK, D. Bioaerosol health effects and exposure assessment: progress and prospects. Annals of Occupational Hygiene, v. 47, n. 3, p. 187–200, 2003.

DOUWES, J.; WOUTERS, I.; DUBBELD, H.; VAN ZWIETEN, L.; STEERENBERG, P.; DOEKES, G.; HEEDERIK, D. Upper airway inflammation assessed by nasal lavage in compost workers: A relation with bio-aerosol exposure. American Journal of Industrial Medicine, v. 37, n. 5, p. 459–468, 2000.

ERIKSEN, E.; MADSEN, A. M.; AFANOU, A. K.; STRAUMFORS, A.; EILER, A.; GRAFF, P. Occupational exposure to inhalable pathogenic microorganisms in waste sorting. International Journal of Hygiene and Environmental Health, v. 253, p. 114240, 2023.

FUMAGALLI, A.; DERUDI, M.; ROTA, R.; COPELLI, S. Estimation of the deflagration index KSt for dust explosions: A review. Journal of Loss Prevention in the Process Industries, v. 44, p. 271–282, 2016.

FUNDAÇÃO JORGE DUPRAT FIGUEIREDO DE SEGURANÇA E MEDICINA DO TRABALHO. Norma de higiene ocupacional: procedimento técnico: coleta de material

particulado sólido suspenso no ar de ambientes de trabalho. São Paulo: Fundacentro, 2007. 24 p. (Normas de higiene ocupacional - NHO; 08). ISBN 978-85-98117-39-3.

HALSTENSEN, A. S.; NORDY, K. C.; EDUARD, W.; et al. Determinants of microbial exposure in grain farming. Annals of Occupational Hygiene, v. 51, n. 7, p. 581–592, 2007.

HANSEN, K. K.; SCHLÜSSNER, V.; BROBERG, K.; ØSTERGAARD, K.; FREDERIKSEN, M. W.; MADSEN, A. M.; KOLSTAD, H. A. Exposure levels of dust, endotoxin, and microorganisms in the Danish recycling industry. Annals of Work Exposures and Health, v. 67, n. 7, p. 816–830, 2023.

HUÉSCAR MEDINA, C.; MACCOITIR, B.; SATTAR, H.; SLATTER, D. J. F.; PHYLAKTOU, H. N.; ANDREWS, G. E.; GIBBS, B. M. Comparison of the explosion characteristics and flame speeds of pulverised coals and biomass in the ISO standard 1 m³ dust explosion equipment. Fuel, v. 151, p. 91–101, 2015.

JOSEPH, P. Domino effect in dust explosions. Journal of Hazardous Materials, v. 143, n. 1-2, p. 10–18, 2007.

KHAN, A. M.; RAY, S. K.; MOHALIK, N. K.; MISHRA, D.; MANDAL, S.; PANDEY, J. K. Experimental and CFD simulation techniques for coal dust explosibility: A review. Mining, Metallurgy & Exploration, v. 39, p. 1445–1463, 2022.

KUAI, N.; HUANG, W.; YUAN, J.; DU, B.; LI, Z.; WU, Y. Experimental investigations of coal dust-inertant mixture explosion behaviors. Procedia Engineering, v. 26, p. 1337–1345, 2011.

LIN, X.; YUAN, Z.; AMYOTTE, P. Suppression of dust explosions using solid powders: Mechanism and application. Powder Technology, v. 366, p. 402–411, 2020.

LOUREIRO, B. A.; ASSIS, M. R.; MELO, I. C. N. A.; OLIVEIRA, A. F. F.; TRUGILHO, P. F. Rendimento gravimétrico da carbonização e caracterização qualitativa do carvão vegetal em clones de híbridos de Corymbia spp para uso industrial. Ciência Florestal, Santa Maria, v. 31, n. 1, p. 214–232, 2021.

MADSEN, A. M.; RASMUSSEN, P. U.; FREDERIKSEN, M. W. Fungal and bacterial species on biowaste workers' hands and inhalation zone, and potential airway deposition. Waste Management, v. 183, p. 290–301, 2024.

MITTAL, M. Limiting oxygen concentration for coal dusts for explosion hazard analysis and safety. Journal of Loss Prevention in the Process Industries, v. 26, n. 6, p. 1106–1112, 2013.

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA). Combustible Dust: Safety and Injury Prevention. Instruction Manual, 1997.

PEIXOTO, N. H.; FERREIRA, L. S. Higiene Ocupacional I. Santa Maria: UFSM, CTISM, 2012.

PROTÁSIO, T. P.; COUTO, A. M.; REIS, A. A.; TRUGILHO, P. F.; GODINHO, T. P. Potencial siderúrgico e energético do carvão vegetal de clones de Eucalyptus spp. aos 42 meses de idade. Pesquisa Florestal Brasileira, Colombo, v. 33, n. 74, p. 137–149, 2013.

REDING, N. S.; SHIFLETT, M. B. Metal dust explosion hazards: A technical review. Industrial & Engineering Chemistry Research, v. 61, n. 36, p. 13242–13256, 2022.

REIS, A. A.; PROTÁSIO, T. P.; MELO, I. C. N. A.; TRUGILHO, P. F.; CARNEIRO, A. C. O. Composição da madeira e do carvão vegetal de Eucalyptus urophylla em diferentes locais de plantio. Pesquisa Florestal Brasileira, Colombo, v. 32, n. 71, p. 277–290, 2012.

SÁ, A. Efeito devastador. Revista Proteção, ed. 181, 2007. Available at: http://www.ufrrj.br/institutos/it/de/acidentes/silo.htm. Accessed on: 20 set. 2026.

SÁ, A. Risco de explosão. Revista Proteção, v. 61, 1997.

SALETNIK, B.; BAJCAR, M.; SALETNIK, A.; ZAGULA, G.; PUCHALSKI, C. Effect of the pyrolysis process applied to waste branches biomass from fruit trees on the calorific value of the biochar and dust explosivity. Energies, v. 14, n. 16, 4898, 2021.

SALIBA, T. M. Manual prático de avaliação e controle de poeira e outros particulados: PPRA. 8. ed. São Paulo: LTr, 2016.

SANTAMARÍA-HERRERA, A.; HOYUELOS, F. J.; CASADO-MARCOS, C. Characterization of the explosiveness of wood dust. Process Safety and Environmental Protection, v. 169, p. 252–259, 2023.

SANTOS, A. M. O tamanho das partículas de poeira suspensas no ar dos ambientes de trabalho. São Paulo: Fundacentro, 2001.

SANTOS, R. C.; CARNEIRO, A. C. O.; PIMENTA, A. S.; CASTRO, R. V. O.; MARINHO, I. V.; TRUGILHO, P. F.; ALVES, I. C. N.; CASTRO, A. F. N. M. Potencial energético da madeira de espécies oriundas de plano de manejo florestal no Estado do Rio Grande do Norte. Ciência Florestal, Santa Maria, v. 23, n. 2, p. 491–502, 2013.

SOUZA, Diene Gonçalves et al. CO_2 monitoring associated with the quality of soybean grains stored in different moisture contents. Food Science and Technology, Campinas, v. 43, e29023, 2023.

THIAGO, L. R. L. de S.; SILVA, J. M. da. Soja na alimentação de bovinos. Campo Grande, MS: Embrapa Gado de Corte, 2003. 6 p. (Embrapa Gado de Corte. Circular técnica, 31).

VINCENT, J. H.; MARK, D.; MILLER, B. G.; ARMBRUSTER, L.; OGDEN, T. L. Aerosol inhalability at higher windspeeds. Journal of Aerosol Science, v. 21, n. 4, p. 577–586, 1990.

XU, J.; XU, K.; LIU, B. Experimental Study on the Characteristics of Bicarbonate Inhibiting Soybean Meal Dust Explosion. Journal of Northeastern University (Natural Science), v. 45, n. 12, p. 1798–1804, 2024.

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