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DRYING AND STORAGE TECHNOLOGIES TO MINIMIZE QUALITY LOSSES IN SOYBEANS IN THE SOUTHERN REGIONS OF BRAZIL

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KEYWORDS

grain conservation, grain quality, food security, soybean postharvest, soybean processing.

ABSTRACT

This study aimed to evaluate, on a real production scale, the management of batches of harvested soybean grains in storage units, which are submitted for different technological processes of drying. The study regions were divided into micro-regions based on structure and static storage capacity. For each micro-region (West, East, North, South, Central), soybeans were dried using a continuous dryer-CD1, a continuous dryer + silo-dryer-CDSD2, and a continuous dryer + aerator-silo-CDAS3. Grain quality losses due to drying management ranged from 0.23 to 3.26% in crude protein, and from 0.15 to 3.05% in crude oil. In regions with large-scale soybean production, adopting storage unit structures at the farm level, ranging from 11 to 19 km, with high drying technology in partial continuous grain flow and final stationary drying in a silo-dryer or silo-aerator is the best alternative for a productive-sustainable system. Managing CDSD2 and CDAS3 soybean drying system is an alternative that ensures low losses and high grain quality, improving protein and crude oil content. In conclusion, the CDSD2 and CDAS3 drying systems reduced crude protein and oil content losses by 94% and 95%, respectively, providing a much better sustainable postharvest system.

INTRODUCTION

In Brazil, the area of grain production has an average increase of 3.5% yearly, and the productivity has risen by approximately 27.7% with an estimated average production of 350 million tons of grain (Conab, 2023). Among the largest grain producing regions, the midwest and south regions have been highlighted, producing main crops such as soybeans, corn, rice, and cotton. Soybean is one of the main agricultural crops produced, standing out with approximately 40% and 20% of crude protein and crude oil, respectively, primarily used for human consumption and animal feed (Brooker et al., 1992; Wang et al., 2015). However, the expansion of soybean production in Brazil brought new challenges, especially in the postharvest stages, causing a significant deficit in static storage capacity in relation to the total grain production. These challenges are directly reflected in the logistics, quality, and marketing prices of the products.

Postharvest quanti-qualitative losses of grains bring about an imbalance in grain production sector. Variations in the water content of the grain mass, as well as temperature and relative humidity of their intergranular air, may influence their storage ecosystem. These factors increase the respiratory rate of the grain mass, causing deterioration of the grains, reduction in dry matter percentage, and contamination by insects, pests, fungi, and mycotoxin production (Ng'ang'a et al., 2016; Babu et al., 2018; Nyabako et al., 2020). To reduce grain losses during storage stage, it is essential that crushed grains are uniform in quality and undergo cleaning and drying processes. Fundamentally, the aim of drying is reducing the moisture of grains for optimum storage conditions, reducing water activity to a level where microbial growth and rate of

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deterioration are slowed. However, the thermal drying process cannot be severe (Opoku et al., 2018; Raza et al., 2019). Besides the removal of moisture, drying may interfere with the physical-chemical structure of grains, promoting breakdown in cellular tissues and accelerating deterioration process of grains (Reyes et al., 2014; Wang et al., 2015; Coradi et al., 2017).

The heterogeneity of harvested grain lots from the beginning to the end of harvesting period hinders the capacities of dryers. Therefore, it is necessary to closely monitor and manage water content in grain mass and their drying air temperature to ensure process optimization of energy consumption and grain quality (Li et al., 2007; Bowser et al., 2011; Samadi et al., 2013). Currently, the energy used in drying comes from natural sources. Due to growing environmental concerns, there is a requirement to further reduce energy consumption in the food sector, which will result in decoupling food prices. Leveraging renewable energy is a desirable means of drying agricultural products, and associating them with current drying technologies will also improve their efficiency vastly, exploring operational drying conditions, enhancing temperature and air flow control (Rabha et al., 2017). An alternative could be the adoption of grain storage distribution units and drying technologies on a regional scale. Hence, the objective of this work was to evaluate, on a real scale of production, the quanti-qualitative losses of soybeans influenced by the regional production, structure, static storage capacity, and drying technologies.

MATERIAL AND METHODS

In the first stage of this study, the structures and static capacity of grain storage were evaluated. Then, a survey of the grain storage units and the logistics of production flow was performed on a regional production basis in Southern Brazil, specifically, the municipality of Cachoeira do Sul, which is considered the second largest grain producer in the state of Rio Grande do Sul. The study region was divided into five micro-regions (South, West, East, North, and Central) based on structure and static storage capacity, temperature and relative humidity of ambient air, and moisture content of grain harvest (Figure 1).

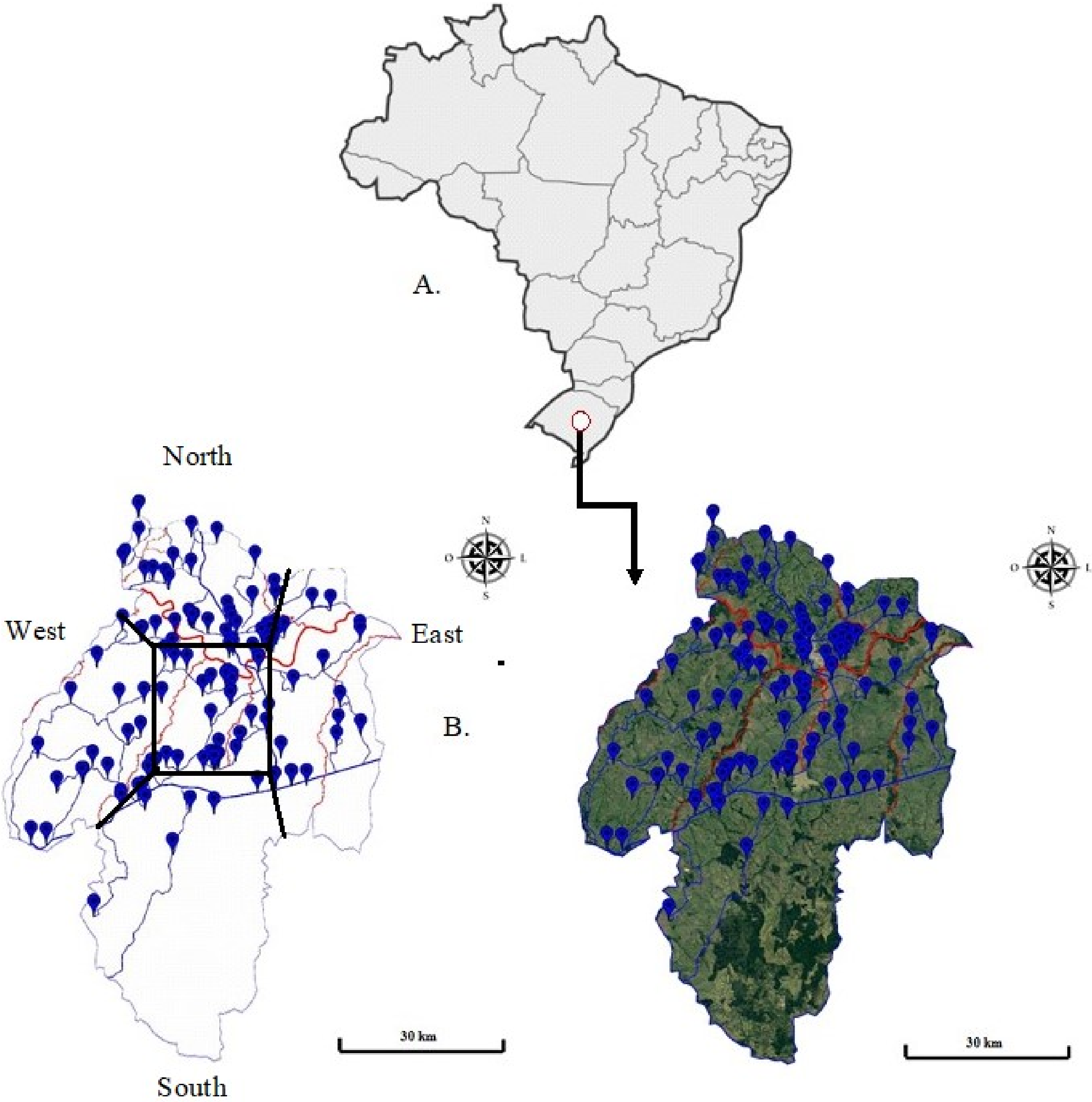

FIGURE 1. Map of Brazil, state of Rio Grande do Sul (A), location of grain storage units in the municipality of Cachoeira do Sul-RS, Brazil (B).

The inventory volumes and characteristics of storage structures in the experimental area were different in the first and second half of the year. In the first half of the year, mostly grains were harvested. During this period, storage in large structures of bulk warehouses for commercialization was predominant (Figures 2A-B). In both storage systems, stocks at farms, service providers, and industries were balanced (Figures 3A-B). In the second half of the year, storage system in vertical silos predominated, followed by storage in bulk warehouses and conventional bulk warehouses, for long-term storage.

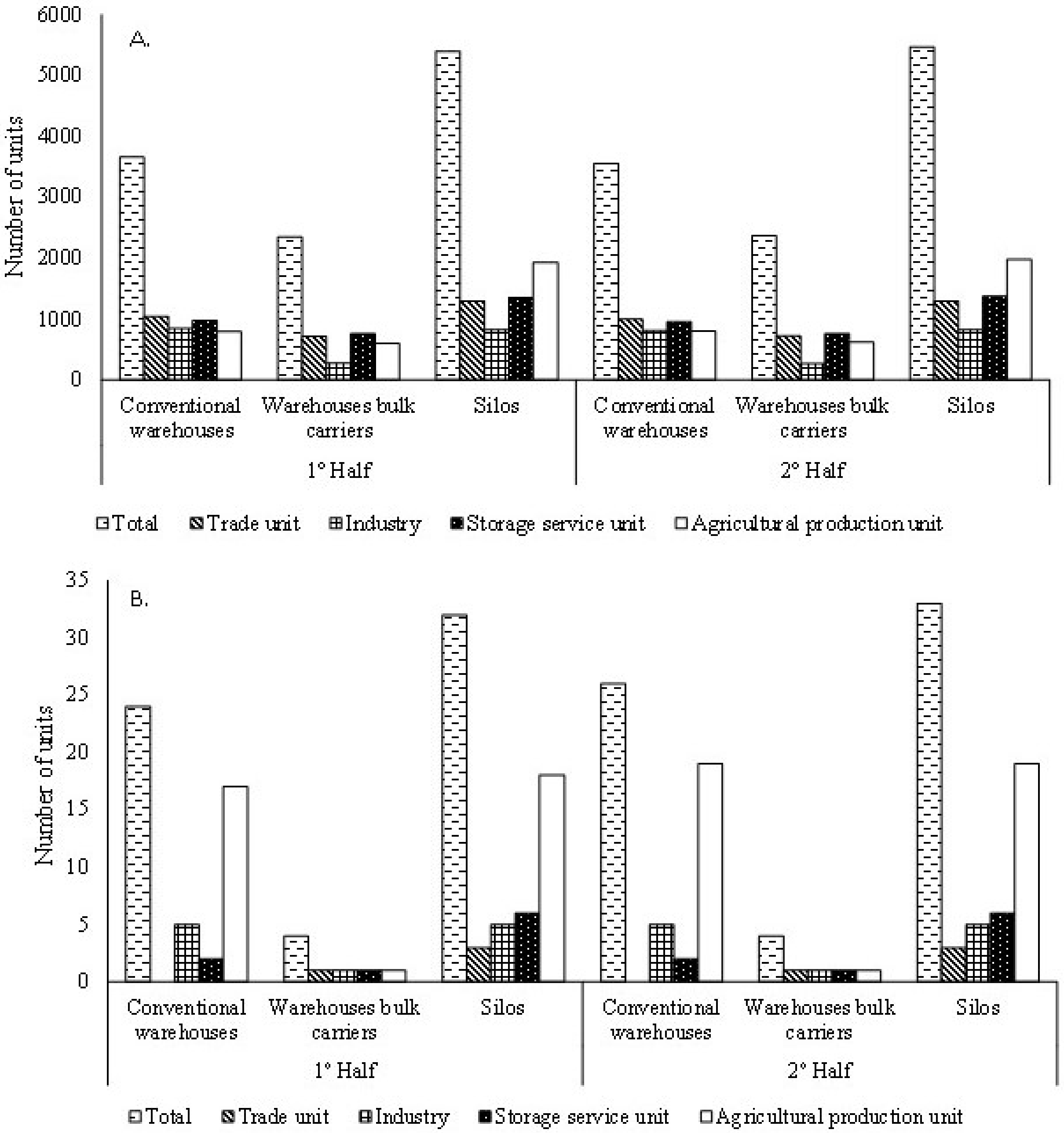

FIGURE 2. Number of grain storage units in operation in Brazil (A) (Conab, 2023). Number of grain storage units in Cachoeira do Sul / RS (B) (IBGE, 2023).

In the northern region, grain storage units were located at an average distance of 19.6 km from main highways, ranging from 0 km to 47.4 km; in the west region, the storage units were located at an average distance of 11.7 km, ranging from 0 km to 27.3 km; in the south, the units were located at an average distance of 5.15 km, ranging from the shortest distance of 12.8 km to the longest distance of 23.1 km; in the east, the units were located at an average distance of 11.3 km, ranging from 0 km to 23.5 km; and in the central region, the units were located at an average distance of 15.2 km, ranging from 0 km to 31.9 km.

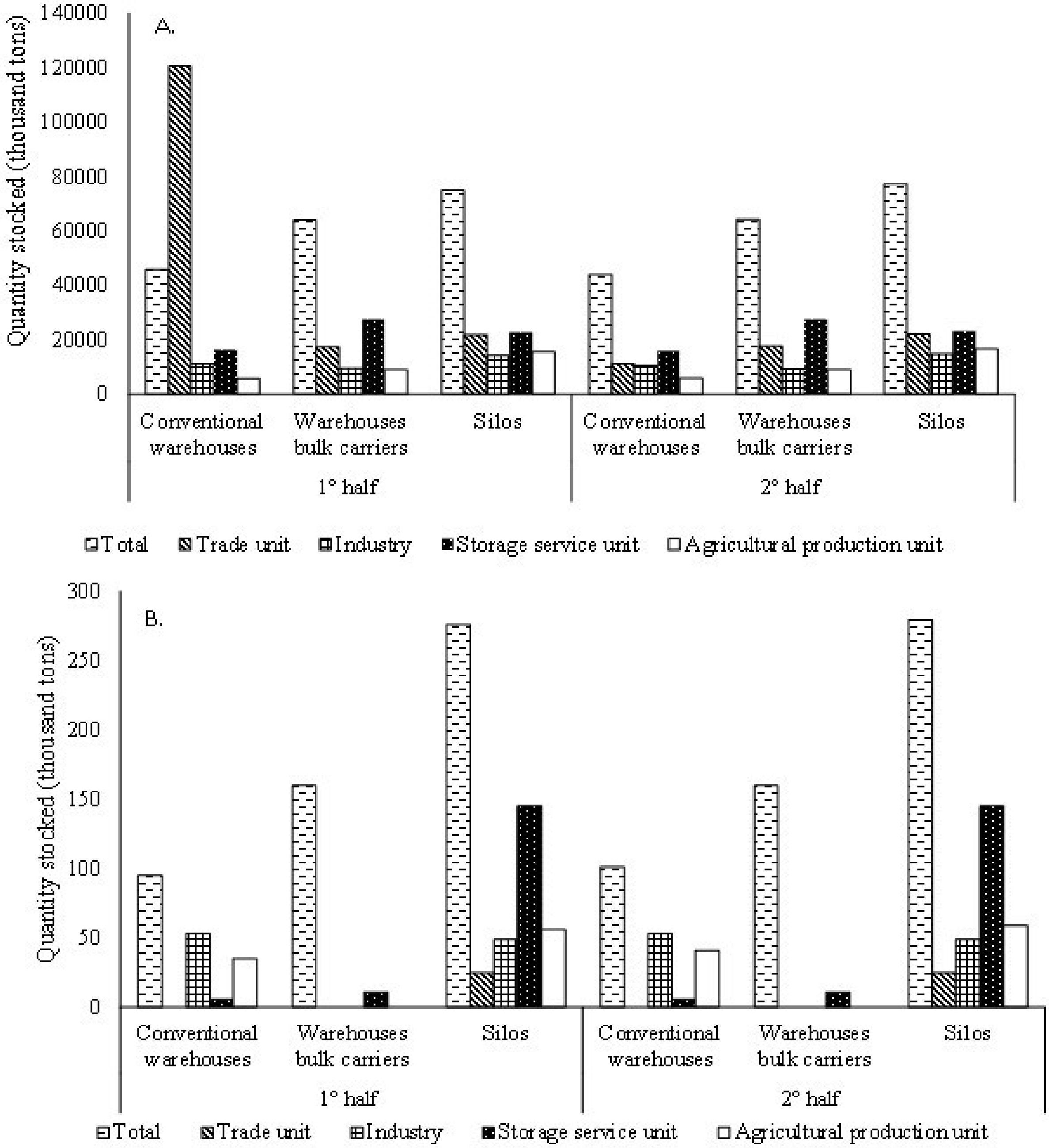

FIGURE 3. Static grain storage capacity in Brazil (A) (Conab, 2023). Static grain storage capacity in Cachoeira do Sul / RS (B) (IBGE, 2023).

The evaluated grain storage units included receiving structures with manual and pneumatic grain extractors with truck unloading manually or with hydraulic system; pre-cleaning and cleaning systems composed of air machines and sieves, flow drying equipment for grain, and air movement in mixed flows; and stationary dryers (silos-dryers). Storage was carried out in elevated metal silos and horizontal bulk silos with an aeration and dry-aeration system. For each micro-region (West, East, North, South, Central) the drying technologies in the storage units were evaluated (dry soybeans in continuous dryer-CD1, continuous dryer + silo-dryer-CDSD2, continuous dryer + aerator-silo-CDAS3) (Figure 4). Average ambient air conditions varied from 55 to 70% relative humidity and 20 to 31 °C temperature during the evaluation period. The soybeans were harvested with moisture contents between 17 and 20%. When drying in CD1, the drying air temperature varied from 80 to 95 °C. When drying in CDSD2, the temperature of the drying air used varied from 80 to 95 °C until the moisture content reached 16%, and in the silo-dryer, the temperature of the dehumidified ambient air (50-60% RH) was used to complete drying. In CDSD3 drying, the drying air temperature was from 80 to 95 °C until the moisture content reached 14%, subsequently, the grains were dried using natural air aeration until reaching 12% water content.

During grain drying, the air temperature was monitored using a thermocouple sensor installed in the dryer itself and positioned in the transition space of the drying chamber (air-grain mixture). The temperature of grain mass was measured during drying; samples were collected at the exit of the dryer with the aid of a container. Temperature and relative humidity sensors were used to monitor the ambient air temperature, drying air, and exhaust air. Samples were placed next to an iodine thermometer to obtain the temperature. Paddle anemometers were used to measure air velocity at the entry and exit of the drying systems.

Grain samples of 1 kg each (total of 146 samples) were collected and sent to a quality control room, where technicians determined their moisture content (M), specific unit mass (ρ_{un}), apparent specific mass (ρ_{ap}), and porosity (ξ) (Mohsenin, 1986). Electrical conductivity (EC) test was performed on soybeans. Four replicates of fifty grains were used for each treatment. The grains were weighed on a digital scale to two decimal places, placed in plastic container (200 mL), and then, 75 mL of deionized water was added to each container (Parmar et al., 2018). The containers were placed in germinator previously set at 25 °C for 24 hours. Subsequently, the containers were removed and gently shaken. An AK51 electric conductivity meter incorporated with automatic calibration and automatic temperature compensation was used for the tests. Results were expressed in $\mu S\ cm^{-1}\ g^{-1}$ (Brazil, 2007).

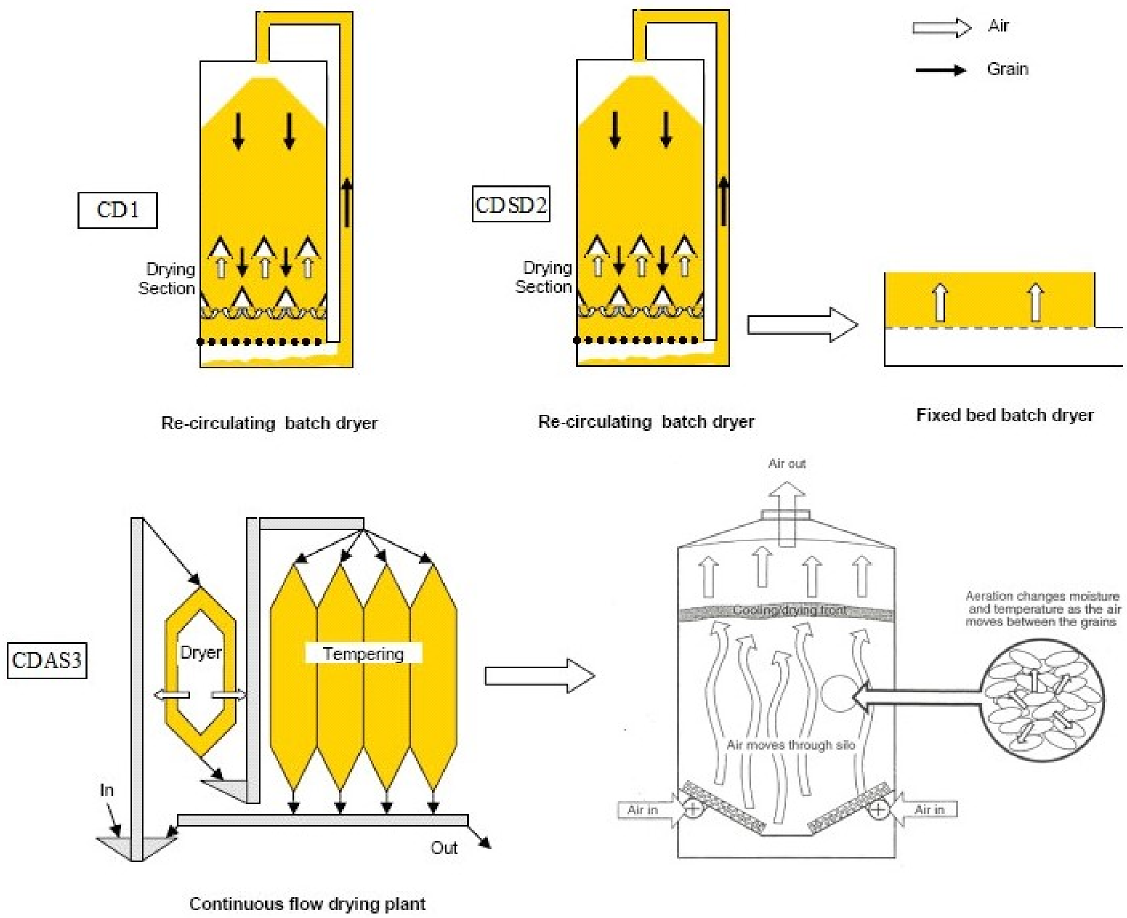

FIGURE 4. CD1 - dry soybeans in continuous dryer, CDSD2 - dry soybeans in continuous dryer + silo-dryer, CDAS3 - dry soybeans in continuous dryer + aerator-silo.

To determine the percentage of dry matter (DM) of soybean samples, the samples were previously ground to fine size after placing them in a drying oven at 105 ºC for 8 h (AOAC, 1984). The percentage of dry matter of the sample was calculated based on the difference between the initial and final weight. Protein content of the soybean sample was determined using the Kjeldahl method (AOAC, 1997). For the determination of Nitrogen (N) content, 0.20 g of sample was measured and placed in a digester block together with a catalyst and sulfuric acid at a temperature of 300 °C. After digestion, 10 mL of distilled water and 5 mL of ammonium borate were added for distillation. After distillation, titration with hydrochloric acid was performed. The process was repeated twice for each sample. For the conversion of N values to crude protein (CP), a correction factor of 6.25 was used, considering 16% nitrogen (100/16 = 6.25).

Lipid contents (ether extract - EE) was determined according to AOCS (2005), using ANKOM XT15 equipment and ANKOM XT4 filter bags. Petroleum ether was used as the solvent for extraction at a temperature of 90 ºC for 60 minutes. After extraction, the beakers were placed in an oven until all the solvent had evaporated. The beakers were then removed from the oven and placed in a desiccator until they reached a constant temperature for weighing. The data obtained were analyzed using analysis of variance, and the resulting means were separated using Tukey test at 5% probability level using Sisvar 5.6 software.

RESULTS AND DISCUSSION

Grain storage distribution units in the study region and the access roads to the main highways for the outflow of grain production satisfactorily met the regional demand. The grain storage units are located, mainly, in the central part of the region, owing to their proximity to main roads, which connect other regions. In the central region, 60% of the soybeans were dried in continuous dryer (CD1), 10% in continuous dryer + silo-dryer (CDSD2), and 30% in continuous dryer + aerator-silo (CDAS3) storage units. In the southern region, 100% of the drying systems were composed of CD1. In the northern region, 35%, 35%, and 30% of the storage units were composed of CD1, CDSD2, and CDAS3 drying systems, respectively. In the western region, 30%, 30%, and 40% of the drying systems were composed of CD1, CDSD2, and CDAS3, respectively. In the eastern region, the drying systems were composed of 30% CD1, 20% CDSD2, and 50% CDAS3. The soybean lots were harvested and submitted for drying management.

The drying technology influenced the time to reduce the moisture content and the temperature of the grain mass. The CD1 dried soybeans took 90 min to reduce the moisture content from 17% to 11.0%, causing an average increase in the temperature of the grain mass from 36 to 41 °C. In contrast, in the soybean batches dried in CDSD2 and CDAS3, the drying time was 60 min, remaining with the same variations in the reduction of moisture contents and increases in the grain mass temperature of the CD1.

The removal of moisture from products through drying results from the difference between the vapor pressure of the grain and that of the air, creating a gradient of vapor tension. The moisture is gradually transferred from the interior of the grain to the periphery, owing to capillary movements, moisture diffusion, and vapor pressure gradients (Mayor & Sereno, 2004). Thus, the drying processes and technology layout of the storage units in the regions affected the quality of soybeans (Table 1). The drying carried out with CDSD2-continuous dryer + silo-dryer, CDAS3-continuous dryer + aerator-silo was more suitable for quality of grains. However, in the central region, where the used drying systems were composed of mass monitoring technologies, grain and drying air minimized the effects of dryer types and distribution of storage units.

Some researches observed a linear reduction in apparent specific mass and unit-specific mass of soybeans with increased drying temperatures. The increase in storage units, based on region, reduced the volume of dry grains per unit, contributing to a low flow of grain lots from the crop to the drying systems, making it possible to use silo-dryer and drying equipment with slow drying rate. In addition, the maintenance of water contents of stored grains when the grains were subjected to drying more evenly, reducing the losses of dry matter and the apparent specific mass of grains (Botelho et al., 2015).

However, improper handling of grain or drying system can cause serious damage to grains. Coradi et al. (2017) described how drying soybeans with a moisture above 19% and air temperature at 120 °C significantly increased the acidity and content of crude oil and protein compared to drying at lower temperatures such as 75, 90, and 105 °C. Others studies evaluated soybeans with moisture content of 23% (w.b.), subjecting them to drying at temperatures of 40, 50, 60, 70, and 80 ºC until the moisture content was 12.5 ± 0.7% (w.b.). The authors concluded that the quality of soybean and crude oil decreases as the drying air temperature increases (Coradi et al., 2020).

The study revealed that as the evaporated moisture mass in a drying process is increasingly smaller, mass of dried product and drying yield was increasingly lower. Moreover, the lower the final moisture content of grains, the more energy the drying process consumes due to a higher fuel mass flow and higher energy efficiency of the dryer. Results obtained from the current study are favorable for a sustainable system, considering the increase in the use of heat sources based on sustainable biomass. This study presents a viable option for grain-producing regions experiencing high energy costs, reducing greenhouse gas and carbon emissions associated with the use of fossil fuels (Kusnandar et al., 2019).

According to the results shown in Table 1, there are significant differences among drying technologies in terms of developing more sustainable systems. Significant losses in grain quality were observed (0.23 to 3.26% crude protein and 0.15 to 3.05% crude oil) in drying management. When high temperatures are used in the drying process, a reduction in the oil and protein content of the grain occurs, in addition to increasing the acidity index of the oil (Bokusheva et al., 2012; Ferreira et al., 2019). The results obtained is similar to those found by Lima et al. (2023), who found proteins of 38.57% in soybeans dried at a temperature of 80°C.

According to Wen et al. (2023), high temperatures drying promoted the formation of disulfide bonds and oxidative modification of soybean isolated protein, such as carboxylation and hydroxylation. With increasing temperature, β-sheet and α-helix shifted to random coil and β-turn. The conformation of soybean isolated protein changed, the solubility decreased and the particle size became smaller as a result of the combination of protein oxidation and chemical bond redistribution. However, the structural integrity of soybean isolated protein was better ensured below 130 °C, soybean isolated protein was severely hydrolyzed at 190 °C. These results provide a theoretical basis for the study of protein modification by dry heating, which is a guideline for controlling the degree of protein denaturation in the food industry.

In terms of oil yield, Maciel et al. (2023) verified that the oil extraction efficiency through the extruding-expelling method under real-scale conditions increased with the decrease in the water content of the processed grain. Soybean processed at 10% moisture resulted in 65% oil extraction efficiency. Further decreases in the processing moisture content resulted in a lower marginal increase in oil extraction efficiency.

Similarly, losses of energy, from firewood use, during drying were from 2.5 to 16.4%. The difference between vapor pressure of grain and air resulted in loss of moisture during drying process (Devahastin & Pitaksuriyarat, 2006). Drying of grain occurs when there is a gradient of vapor tension between grain and air, gradually transferring moisture from the interior of grain to their periphery owing to capillary movements, moisture diffusion, and vapor pressure gradients (Darvishi et al., 2015). This means that the warmer the air, the more moisture is retained, and the better the grain surface dries out (Taşeri et al., 2018). According to these principles, drying process may be fast or slow depending on the drying technology system and energy use. Regarding energy utilization and grain quality, this study reveals a predominant continuous grain flow and fast drying (Shapiro-Garza et al., 2020).

Regarding operational aspects of production, making postharvest systems more sustainable plays a significant role in reducing losses. Considering the yield and thermal utilization of dryers, proper use of different technologies allows drying of agricultural products in a sustainable way, ensuring the quality of agricultural products, and reducing losses in physical and chemical characteristics (Stathers et al., 2020).

Thus, it is estimated that the real values of postharvest quanti-qualitative losses are obtained within the productive context of a region with appropriate local characteristics. Factors such as drying technologies and grain flows delineate parameters for a model to control and manage soybeans during postharvest, with the lowest percentages of potential losses (Bakhtavar et al., 2019). In the regional context, it was observed that static storage capacity of the evaluated region matched the production of grains, owing to the predominant use of storage service provider units.

TABLE 1. Physical and physicochemical quality of soybean grain lots handled in the drying.

Microrregions	Analysis	Drying systems		
		CD1	CDSD2	CDAS3
Central Region	M (%)	12.31 $^{\pm 0.56}$ A	12.85 $^{\pm 0.47}$ A	12.20 $^{\pm 0.51}$ A
	DM (%)	86.69 $^{\pm 1.38}$ A	84.15 $^{\pm 1.43}$ B	83.80 $^{\pm 1.56}$ C
	CP (%)	42.64 $^{\pm 0.85}$ A	42.02 $^{\pm 0.75}$ A	39.61 $^{\pm 0.88}$ B
	EE (%)	23.41 $^{\pm 1.10}$ A	23.52 $^{\pm 1.08}$ A	23.34 $^{\pm 1.06}$ A
	ρ_{un} (kg m^{-3})	955.20 $^{\pm 10.16}$ C	965.20 $^{\pm 13.71}$ B	971.64 $^{\pm 9.23}$ A
	ρ_{ap} (kg m^{-3})	643.06 $^{\pm 7.32}$ B	633.45 $^{\pm 8.67}$ C	650.05 $^{\pm 8.32}$ A
	ξ (%)	32.67 $^{\pm 3.21}$ A	34.42 $^{\pm 2.45}$ A	33.11 $^{\pm 2.89}$ A
	EC (µS cm^{-1} g^{-1})	133.45 $^{\pm 13.52}$ A	120.67 $^{\pm 15.68}$ B	51.78 $^{\pm 5.32}$ C
South Region	M (%)	12.18 $^{\pm 0.66}$ A	12.24 $^{\pm 0.59}$ A	12.67 $^{\pm 0.61}$ A
	DM (%)	83.19 $^{\pm 1.62}$ B	84.65 $^{\pm 1.81}$ A	84.31 $^{\pm 1.97}$ A
	CP (%)	41.86 $^{\pm 0.97}$ B	42.66 $^{\pm 0.82}$ A	42.15 $^{\pm 0.82}$ A
	EE (%)	21.01 $^{\pm 1.18}$ B	21.12 $^{\pm 1.26}$ B	22.24 $^{\pm 1.43}$ A
	ρ_{un} (kg m^{-3})	920.20 $^{\pm 12.47}$ A	918.20 $^{\pm 13.51}$ B	914.14 $^{\pm 15.92}$ C
	ρ_{ap} (kg m^{-3})	618.36 $^{\pm 9.19}$ A	618.35 $^{\pm 10.51}$ A	615.15 $^{\pm 10.63}$ A
	ξ (%)	31.27 $^{\pm 4.19}$ A	31.22 $^{\pm 5.65}$ A	31.22 $^{\pm 7.24}$ A
	EC (µS cm^{-1} g^{-1})	155.25 $^{\pm 17.06}$ A	136.67 $^{\pm 14.00}$ B	67.78 $^{\pm 17.45}$ C
North Region	M (%)	12.62 $^{\pm 0.61}$ A	12.16 $^{\pm 0.59}$ A	12.51 $^{\pm 0.61}$ A
	DM (%)	86.19 $^{\pm 1.50}$ A	83.65 $^{\pm 1.81}$ B	83.3 $^{\pm 1.97}$ B
	CP (%)	42.38 $^{\pm 0.91}$ A	41.76 $^{\pm 0.82}$ B	39.35 $^{\pm 0.82}$ C
	EE (%)	22.81 $^{\pm 1.14}$ A	22.92 $^{\pm 1.26}$ A	22.74 $^{\pm 1.43}$ A
	ρ_{un} (kg m^{-3})	928.2 $^{\pm 11.32}$ C	938.2 $^{\pm 13.51}$ B	944.64 $^{\pm 15.92}$ A
	ρ_{ap} (kg m^{-3})	628.06 $^{\pm 8.26}$ B	618.45 $^{\pm 10.51}$ C	635.05 $^{\pm 10.63}$ A
	ξ (%)	32.77 $^{\pm 3.70}$ C	34.52 $^{\pm 5.65}$ A	33.21 $^{\pm 7.24}$ B
	EC (µS cm^{-1} g^{-1})	149.45 $^{\pm 15.29}$	136.67 $^{\pm 14.00}$	67.78 $^{\pm 17.45}$
Eastern Region	M (%)	12.45 $^{\pm 0.71}$ A	12.99 $^{\pm 0.71}$ A	12.34 $^{\pm 0.55}$ A
	DM (%)	86.39 $^{\pm 1.74}$ A	83.85 $^{\pm 2.07}$ B	83.5 $^{\pm 1.84}$ B
	CP (%)	42.42 $^{\pm 1.03}$ A	41.8 $^{\pm 0.96}$ B	39.39 $^{\pm 0.75}$ C
	EE (%)	22.91 $^{\pm 1.22}$ A	23.02 $^{\pm 1.32}$ A	22.84 $^{\pm 1.40}$ A
	ρ_{un} (kg m^{-3})	930.2 $^{\pm 13.63}$ C	940.2 $^{\pm 15.89}$ B	946.64 $^{\pm 14.73}$ A
	ρ_{ap} (kg m^{-3})	635.06 $^{\pm 10.13}$ B	625.45 $^{\pm 12.47}$ C	642.05 $^{\pm 9.65}$ A
	ξ (%)	32.78 $^{\pm 4.68}$ C	34.53 $^{\pm 6.43}$ A	33.22 $^{\pm 6.85}$ B
	EC (µS cm^{-1} g^{-1})	143.45 $^{\pm 18.83}$ A	130.67 $^{\pm 18.56}$ B	61.78 $^{\pm 15.17}$ C
West Region	M (%)	12.11 $^{\pm 0.69}$ A	12.34 $^{\pm 0.68}$ A	12.03 $^{\pm 0.67}$ A
	DM (%)	84.99 $^{\pm 1.68}$ A	84.79 $^{\pm 2.01}$ A	84.00 $^{\pm 2.10}$ A
	CP (%)	41.52 $^{\pm 1.00}$ A	41.18 $^{\pm 0.93}$ A	41.52 $^{\pm 0.89}$ A
	EE (%)	20.85 $^{\pm 1.20}$ A	20.69 $^{\pm 1.31}$ A	20.85 $^{\pm 1.46}$ A
	ρ_{un} (kg m^{-3})	916.8 $^{\pm 13.05}$ A	913.4 $^{\pm 15.30}$ B	916.8 $^{\pm 17.11}$ A
	ρ_{ap} (kg m^{-3})	614.15 $^{\pm 9.66}$ A	609.94 $^{\pm 11.98}$ B	614.15 $^{\pm 11.61}$ A
	ξ (%)	31.13 $^{\pm 4.44}$ A	30.99 $^{\pm 6.24}$ A	31.13 $^{\pm 7.63}$ A
	EC (µS cm^{-1} g^{-1})	163.25 $^{\pm 17.95}$ B	171.25 $^{\pm 17.42}$ A	163.25 $^{\pm 19.73}$ B

M - moisture content, DM - dry matter, CP - crude protein, EE - ethereal extract, ρ_{un}- specific unit mass, ρ_{ap} - apparent specific mass, ξ - porosity, EC - electrical conductivity. CD1-dry soybeans in continuous dryer, CDSD2-continuous dryer + silo-dryer, CDAS3-continuous dryer + aerator-silo-CDAS3. Averages followed by the same letter in the line do not differ from each other at 5% probability.

Over the years, there have been results similar to and that corroborate the results of the current study. Analyzing the storage capacity in the regions, Brazil has always had a deficit in storage structures and that the surpluses observed in recent years were due to reduction in production, owing to observed climatic adversities and not an increase in static storage capacity (Bakhtavar & Afzal, 2020).

In recent years, static storage capacity in Brazil has not maintained pace with crop increase. Therefore, there is space in critical regions to better adapt and expand storage, as a means of helping producers retain their production, so as to keep up with the best seasons and even avoid major congestion in ports, warehouses, and silos. These same researchers warned against the mistake that could be made when issues of static storage capacity are simply confronted based on production, because, in practice, harvests do not commensurate storage capacities and entire products are not harvested simultaneously. Similarly, not all harvested crops are stored; some could be exported or readily sold to consumer in the market. In addition, price quotations also determine the dynamics of marketing and storage. Thus, a universal parameter was proposed to deal with inventory turnover and would serve as an indicator of technical and economic viability of dynamic storage capacity (Medeiros et al., 2020).

Mourtzinis et al. (2019) analyzed the relationship between production and storage capacity of agricultural products, in dynamic perspectives of the regions. The average production from 2005 to 2008 harvests was calculated to generate the dynamic storage availability index and suggest a critical situation for most of the surveyed micro-regions. For a more complete analysis, it would also be necessary for the National Register of Storage Units to include those units owned by rural producers, who do not have the National Register of Legal Entities but have significant storage capacity (Amjad et al., 2015).

Rocha et al. (2019) analyzed the possibility of logistical gains through storage of grain from soybean market by producers in the region of Sorriso, state of Mato Grosso, at different periods, during the years 2009, 2010, and 2011. Their results indicate that storage strategy should be evaluated. Parmar et al. (2018) studied the storage infrastructure and grain flow. Among the results obtained, the author identified a shortage of 41.85% in storage capacity, which is equivalent to over 20 million tons. They also noted that the current logistics employed are inefficient and do not integrate postharvest with product distribution. The author suggested storage at a farm-level as an alternative to reducing losses and adding value to product.

In regions with large-scale soybean production, the adoption of storage unit structures at farm-level ranging from 11 to 19 km; depending on the volume of grains, along with high drying technology involving continuous grain flow, and final stationary drying in silo-dryer or silo-aerator, represents the best alternative for a productive-sustainable system in soybean and energy quality, reducing losses by increasing the potential of resources applied during postharvest. Managing CDSD2 and CDAS3 soybean drying is an alternative that ensures low losses and high grain quality and improves protein and crude oil content; therefore, energy impacts is reduced and efficiency of the drying system is increased.

CONCLUSIONS

This study concludes that the CDSD2 and CDAS3 drying system reduces the physical, crude protein and oil content losses until 95%. In conclusion, postharvest quanti-qualitative losses of grains create an imbalance in the grain production sector, and the variation of moisture content of grain mass and temperature and relative humidity of their intergranular air may influence their storage ecosystem. To reduce grain losses during storage stage, it is essential that crushed grains are uniform in quality and undergo cleaning and drying processes. The heterogeneity of harvested grain lots from the beginning to the end of harvesting period hinders the capacities of dryers. Therefore, it is necessary to closely monitor and manage moisture content in grain mass and their drying air temperature to ensure process optimization.

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Conflict of Interest

The authors declare that they have no conflict of interest.

Author's Contributions

REL: Conceptualization, Investigation, Writing – Original Draft Preparation. **PCC:** Conceptualization, Investigation, Supervision, Visualization, Writing – Review & Editing. **DML**: Investigation, Supervision, Visualization, Writing – Review & Editing**. LPRT:** Investigation, Supervision, Visualization, Writing – Review & Editing**. PET:** Investigation, Supervision, Visualization, Writing – Review & Editing

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