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Pre-harvesting, harvesting, and transport of soybean to brazilian ports: Bioeconomic losses

Pré-colheita, colheita e transporte de soja para portos brasileiros: Perdas bioeconômicas

Pre-cosecha, cosecha y transporte de soja a puertos brasileños: Pérdidas bioeconómicas

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Abstract

The objective of this review was to carry out a scientific systematization on the logistics of soybean chain in Brazil, focusing on losses during harvest, storage, and transport of soy, to demonstrate the economic impacts of losses in the soybean chain. The survey of works related to the theme was conducted in the bases Scopus, SciELO, and in the CAPES portal. In the development of the review, 10 articles were used about the logistics of soybeans in Brazil, 22 studies related to losses in the pre-harvest and soybean harvest, 22 involving soybean transportation and storage losses. The organization of the Brazilian soybean chain is complex due to soybean expansion and the territorial extension of Brazil. The pre-harvest and harvest losses are well explained, but significant losses still occur due to lack of regulation in the harvesters, which can be solved through the training of the operators. Concerning losses during transport and storage, studies are needed to quantify quantitative losses, as these losses may be determinant for the rural entrepreneur's profitability, as well as for the Brazilian competitiveness in the international market in terms of costs.

Keywords: Storage; Harvester; Commodities; *Glycine max*; Transport; Regulation.

Resumo

O objetivo desta revisão foi realizar uma sistematização científica sobre a logística da cadeia da soja no Brasil, com ênfase nas perdas durante os processos de colheita e transporte, para demonstrar os impactos econômicos das perdas na cadeia da soja. O levantamento dos trabalhos relacionados ao tema foi realizado nas bases Scopus, SciELO e no portal CAPES. No desenvolvimento da revisão, foram utilizados 10 artigos sobre a logística da soja no Brasil, 23 estudos relacionados a perdas na pré-colheita e colheita da soja, 22 envolvendo perdas no transporte e armazenamento da soja. A organização da cadeia da soja brasileira é complexa devido à expansão da soja e à extensão territorial do Brasil. As perdas na pré-colheita e na colheita são bem explicadas, mas ainda ocorrem perdas significativas por falta de regulagem nas colhedoras, que podem ser resolvidas com o treinamento dos operadores. Com relação às perdas durante o transporte e armazenamento, estudos são necessários para quantificar as perdas quantitativas, uma vez que essas perdas podem ser determinantes para a lucratividade do empresário rural, bem como para a competitividade brasileira no mercado internacional em termos de custos.

Palavras-chave: Armazenagem; Colheitadeira; Commodities; *Glycine max*; Transporte; Regulagem.

Resumen

El propósito de esta revisión fue realizar una sistematización científica sobre la logística de la cadena de la soja en Brasil, con énfasis en las pérdidas durante la cosecha, el almacenamiento y el transporte de soja, para demostrar los impactos económicos de las pérdidas en la cadena de la soja. El relevamiento de los trabajos relacionados con el tema se realizó en los sitios web

de Scopus, SciELO y CAPES. En el desarrollo de la revisión se utilizaron 10 artículos sobre la logística de la soja en Brasil, 23 estudios relacionados con pérdidas en la pre-cosecha y cosecha de soja, 22 involucrando pérdidas en el transporte y almacenamiento de soja. La organización de la cadena de la soja brasileña es compleja debido a la expansión de la soja y la extensión territorial de Brasil. Las pérdidas en la precosecha y cosecha están bien explicadas, pero aún se producen pérdidas importantes por la falta de regulación en las cosechadoras, que se pueden solucionar con la formación de los operarios. En cuanto a las pérdidas durante el transporte y almacenamiento, son necesarios estudios para cuantificar las pérdidas cuantitativas, ya que estas pérdidas pueden ser determinantes para la rentabilidad de los empresarios rurales, así como para la competitividad brasileña en el mercado internacional en términos de costos.
Palabras clave: Almacenamiento; Cosechadora; Materias primas; Glycine max; Transporte; Regulación.

1. Introduction

Agribusiness is characterized as a sector with the greatest prominence in the Brazilian economy, representing 21.4% of the Brazilian gross domestic product (GDP), according to an estimate by the Confederação da Agricultura e Pecuária do Brasil (CEPEA, 2020). Soybean production (Glycine max) presents itself as the main primary product responsible for the global production of food on a large scale for humans and animals. It still has high added commercial value, due to its historical positive correlation in the future market between the agricultural commodities and stock market financial institutions that invest to ensure the security and liquidity of their investment. All these facts make soybean one of the most liquid commodities on the world market (Hirakuri and Lazzarotto, 2014; Ludwig, 2019; Ordu et al., 2018). Therefore, soybean production in 2017 reached a gross value of BRL 127.7 billion (US$38.58 billion), representing BRL 103.27 million (US$ 31.2 billion) of the Brazilian agribusiness GDP (CNA, 2017; Centro de Estudos Avançados em Economia Aplicada - CEPEA, 2017).

In this context, Brazilian soybean production has shown gradual increases in recent years, surpassing record levels of productivity and reaching historical levels of profitability. The fact is mainly due to technological innovations in research and development adopted in agriculture through public and private collaborative companies, through various segments such as seeds, agrochemicals, machines, agricultural practices adopted, and the dissemination of knowledge. Mainly by the adoption of the no-tillage system, with the use of minimum cultivation, has reduced the critical impacts on the soil sustainability, increasing the amount of water that infiltrates the soil and the retention of organic matter, decreasing water eutrophication, improving biological fertility, increasing the nutrient cycle, and making the soils more resilient and fertile (Figueiredo, 2016; Silva et al., 2017; Zortea et al., 2017).

For the 2018/2019 harvest, Brazil cultivated 35.8 million hectares with a total production of 115 million tons of grain (Companhia Nacional de Abastecimento - CONAB, 2020). While the IBGE (2004) estimates for pre-harvest, harvest, transport, and storage losses approximately 12.5% of the total soy that is produced in the country. Related topre-harvest and harvest losses representing around 4%. Considering the average Brazilian productivity of 3,206 kg ha^{-1}, 4.6 million tonnes of commercial crops are lost, corresponding to a relative 4% of total production, which directly impacts the final production result and, consequently, the profitability of the sector.

Assessing the negative environmental impacts of using fossil fuels for the transportation and production of residues from the spilling of soybeans along the highways Demetino & Maceno (2017), highlighted the importance of studying oilseed losses throughout its chain, in cultivation, during transport, and in storage. Thus, considering the direct and indirect economic impacts of soy losses, the objective was to carry out a scientific systematization on the logistics of the soy chain in Brazil, focusing on losses during harvest, storage, and transport of soy to gather information, quantifying physical losses, and assess their economic impacts on the soybean chain.

2. Methodology

The scientific systematization was carried out through a literature review on the logistics of the soybean production chain in Brazil, taking into account losses during the harvesting processes, which begins in the pre-harvest, harvest, storage (Property, Cooperatives, Companies...), and grain transport to ports, focusing in reports from the past two decades.

The investigation was performed in the Scopus, SciELO, and Coordination for the Improvement of Higher Education Personnel – CAPES portal (https // www.periodicos.capes.gov.br). The terms used to search were losses in pre-harvest of soybeans, harvest, logistics, transport, and storage.

In the development of the review, 10 papers referring to soybean logistics in Brazil were used; 25 studies related to losses in the pre-harvest and harvest of soybean; 23 involving losses in soybean transport and storage, as well sites, followed by the number of articles: from the Confederação da Agricultura e Pecuária do Brasil – CNA (1), Centro de Estudos Avançados em Economia Aplicada – CEPEA (2), Instituto Brasileiro de Geografia e Estatística – IBGE (1), Companhia Nacional de Abastecimento – CONAB (2), Confederação Nacional dos Transportes – CNT (1), Associação Brasileira de Produtores de Soja – APROSOJA (1), Food Agriculture Organization of United Nations – FAO and Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA (6). The papers above were listed and presented according to the topic addressed in Table 1.

Table 1. List of papers by author and theme addressed according to the subjects used in the development of the review on harvest losses at ports.

Authors and year	**Topics covered**
Soybean logistics in Brazil	
Almeida et al. (2013)	Percentage of road transport
Biaggioni and Bovolenta (2010)	Spending on road transport
Correa and Ramos (2010)	Transport costs
Cruz et al. (2009)	Storage improves competitiveness
Dalmás et al. (2009)	Preference for road transport
Demetino and Maceno (2017)	Percentage of road transport
Figueiredo (2016)	New challenges for public research organizations in agricultural innovation in developing economies
Ojima and Yamakami (2006)	Transport costs
Pontes et al. (2009)	Efficiency of the logistics system improve competitiveness
Zortea et al. (2017)	Sustainability assessment of soybean production in Southern Brazil: A life cycle approach
Pre-harvest and harvest losses	
Acosta et al. (2018)	Total crop losses
Bauer and Gonzatti (2007)	Losses due to moisture content

Bock et al. (2020)	Losses in soybean harvest as a function of speed
Campos et al. (2005)	Harvest losses
Cassia et al. (2015)	Monitoring of mechanized soybean harvesting operation
Cara et al. (2018)	Estimated losses in mechanized soybean harvesting, due to different adjustments and displacement speeds
Chioderoli et. al. (2012)	Losses due to delay in harvest
Compagnon et al. (2012)	Losses due to harvest time
Faggion et al. (2017)	Total crop losses
Fernandes et al. (2018)	Losses in soybean harvest
Ferreira et al. (2007)	Quantitative losses in soybean harvest, due to the speed of travel and adjustments in the trail system
Holtz and Reis (2013)	Losses due to harvest time
Kumar and Kalita (2017)	Critical factors in the harvest
Machado et al. (2012)	Adjustment losses
Maranhão e Vieira (2017)	International Insertion of Brazilian Agribusiness
Menezes et al. (2018)	Platform type
Ordu et al. (2018)	Is food financialized? Yes, but only when liquidity is abundant
Pinheiro Neto and Troli (2003)	Operator training
Schanoski et al. (2011)	Combine harvester
Silva et. al, (2017)	Productivity based on climate projections
Silva et. Al. (2013)	High technology losses
Souza et al. (2001)	Axial harvester losses
Toledo et al. (2008)	Losses and crop residue cover distribution in soybean mechanized harvest
Vieira et al. (2006)	Losses at different harvest speeds
Zandonadi et al. (2015)	Total crop losses
Losses in soybean transport and storage	
An and Ouyang (2016)	Robust grain supply chain design considering post-harvest loss and harvest timing equilibrium

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Barreto and Ribeiro (2020)	Panorama of road and rail modes
Bonfim et al. (2013)	Losses in transport and storage
Caixeta-Filho and Péra (2018)	Post-harvest losses during the transportation of grains from farms to aggregation points
Costa et al., (2014)	Socioeconomic impacts of reductions in post-harvest losses of agricultural products in Brazil
Danao et al. (2015)	Factors affecting soy transport
França-Neto and Henning (1984)	Physiological and sanitary qualities of soybean seeds
Gustavsson et al. (2011)	Global food losses and food waste
Kumar and Kalita (2017)	Post-harvest losses and factors that cause losses
Kussano and Batalha (2012)	Transport losses
Ludwig (2019)	Speculation and its impact on liquidity in commodity markets
Novaes et al. (2006)	Road, rail, or maritime cabotage? The use of the declared preference technique to assess intermodally in Brazil
Oliveira et al. (2014)	Quantitative losses on the mechanized harvesting of soy in the region of Cáceres.
Rocha et al., (2015)	Logistics - Impact on revenue of soybean producers
Silva and Marujo (2012)	Road transport
Souza and Uchôa (2019)	Railway modal
Stuart (2009)	The Global Food Scandal
Stewart (2009)	Brazil hit a logistics wall
Tsukahara et al (2016)	Harvest delay losses
Ziegler et al., (2016a)	Effect of temperature and humidity on storage
Ziegler et al., (2016b)	Storage time

Zorya (2011)	Missing food: the case of postharvest grain losses in sub-Saharan Africa
Zuffo et al. (2017)	Harvest delay losses

Source: Authors.

3. Results and Discussion

3.1. Soybean logistics in Brazil

Brazil is currently the largest exporter of soybeans in the world, with 63.8% of the soybeans produced are exported, and China the largest buyer with 58.2 million tons (CONAB, 2020). In the world scenario between harvests from 2000 to 2019, the world consumption of soybean reached 100%, reaching 343.2 million tons with an increase in production of 102%, reaching 358.6 million tons in this period. Grain exports reached 148.3 million tons, the main destination is China, which exported a total of 102 million tons. About 84.7% of the world soybean consumption is destined for crushing, of which 76% is sent to the feed agribusiness and the remainder to oil production (EMPRAPA, 2014; United States Department of Agriculture - USDA, 2020). In this context, the transport logistics, which is concentrated in the road modal, is responsible for the soybean transport to the ports (CNT, 2018).

According to Figueiredo (2016), Brazil achieved production records and incredible growth in agricultural productivity, with emphasis on soybean. Thus, the emergence of the Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA), in the 1970s, played a decisive role to expand agricultural frontiers. This research company supplied innovative management techniques, technical support for rural producers, consolidating the soybean culture in the country. All these facts, have made Brazil one of the main world producers of grains. Despite having the lowest production costs concerning the main world producers, according to Correa and Ramos (2010) the Brazilian soybean, reaches the main export ports as the most expensive, due to transport costs and, consequently, it losses competitiveness in the foreign market.

For Ojima and Yamakami (2006) the transport system is a crucial point. Transport represents most of the commercializing costs of soy, reducing the competitiveness of Brazilian soybean exports to the international market. Biaggioni and Bovolenta (2010) reported that the road modal is more used, however, it presents higher energy expenditure

(0.50 MJ km^{-1} t^{-1}) compared to the railway (0.42 MJ km^{-1} t^{-1}) and waterway (0.22 MJ km^{-1} t^{-1}).

In Brazil, the main transport means used for soybeans and its derivatives is the road with 61.1%, while the railroad represents 20.7% and the waterway only 13.6% (CNT, 2018). The preference for road transport occurs due to the lack of logistical infrastructure of the other modes (Dalmás et al., 2009). The Brazilian road network is 1,720,700 km, of which only 213,453 km (20%) are paved (CNT, 2018). According to Almeida et al. (2013) and Demetino and Maceno (2017) 67 and 61.1%, respectively, of soybean transportation is by road.

For Almeida et al. (2013) road transport is better classified in the total set of assignments speed (time), availability (serving a specific location), reliability (variance in scheduled delivery power), capacity (ability to handle any requirement), and frequency (amount of scheduled movements). In this sense, the different modes are classified and the lower the score, the better is the classification. The road is the first and most used in Brazil, followed by rail, air, pipeline, and waterway. However, Correa and Ramos (2010) and Rocha et al. (2015) pointed out that 14 to 25% of sales revenue from soybean production is committed to internal transportation costs. This fact is, due to the inadequacy of this mode, the product's characteristics and the long distances traveled, combined with the precarious state of conservation of the road network in Brazil. According to data from Novaes et al. (2006) and the Agência Nacional de Transportes Terrestres (ANTT, 2020), the deficiency of investments in road freight transport in Brazil corroborates with the operation of inefficient carriers. These are decapitalized in activity, such as also with the circulation of scrapped trucks, which has an average age of the fleet of 18 years for self-employed professionals, 10.6 years for cooperatives, and 9.5 years for private companies. Thus, it affects the driver's well-being and the high maintenance of the trucks, generating low results for the owner and risks to third parties during transport on the highways.

The lack of storage infrastructure in Brazil forces producers to trade a significant part of soybeans at the time of harvest. Also forces companies and trading to export, transporting their grains at harvest time, causing congestion in ports and export elevators. In 2013, the excess of sales and the lack of storage, combined with a super harvest, caused a line of 64 kilometers of trucks to wait on the highways to unload soybeans at the port of Santos and railway terminals in Araguaia, Brazil (Stewart, 2013).

Post-harvest losses differ by crop and grain-producing region, varying up to 10% of total grain production in developed countries (Gustavsson et al., 2011) and up to 20% in developing countries (Zorya et al., 2011). The reduction of post-harvest losses may help to

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improve global food security, but currently, they cause an increase in food prices for the costumers and the increasing use of grains, such as corn and soybeans, in the production of biofuels (FAO, 2014). According to An and Ouyang (2016), the reduction of post-harvest losses in Brazil is not only important for its agricultural development but also the food security of the country and the world.

Soybean losses occur throughout the processes of the entire soybean production chain. It is established since the beginning of the initial harvesting process, passing to short transport, which goes from the fields to the local warehouse, for storage, and continues through of transport along the outflow highways to the ports destined for export (Figure 1). Despite the considerable impact on the Brazilian economy, the information on the percentage of losses, is not easily available, especially about the quantification of losses in the different extracts of the soybean chain. This fact needs to be considered, since a total of 12.5% of soybean is lost from the harvest to the ports within Brazilian territory, which corresponds to a loss of 14.38 million tons of grain, of the total produced of 117 million tons in harvest 2019/2020 (CONAB, 2020).

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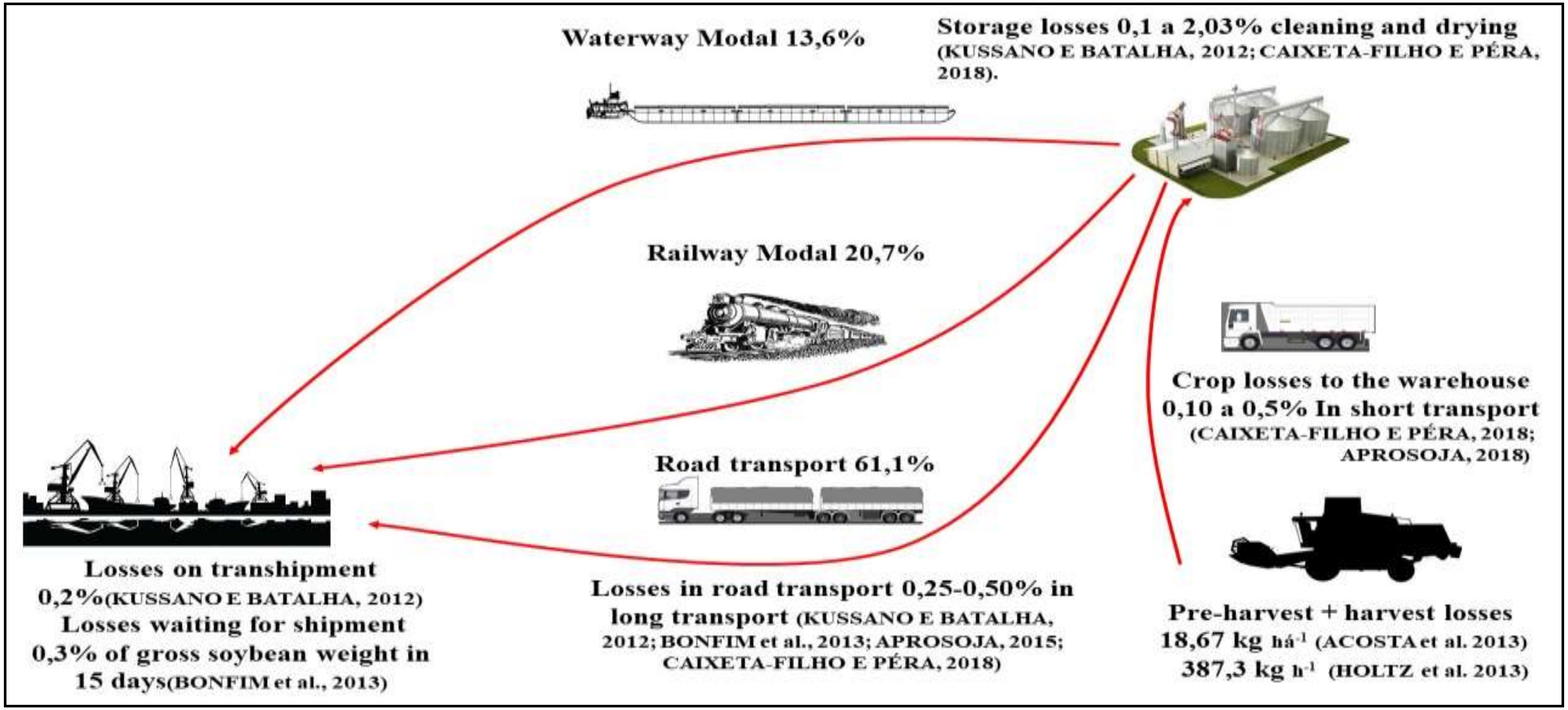
Figure 1. Schematic representation of soybean grain losses in Brazil, from pre-harvest to ports.



Source: Authors.

Since the average productivity of the state of Rio Grande do Sul (3,177 kg/ha) it is equivalent to a harvested area of 4.64 million hectares, corresponding to 80% of the soybean area harvested in the State that was 5.78 million hectares, based on the production of the 2018/2019. This production sold an average price of BRL 77.00 a bag, which would result in BRL 18.46 billion that stopped moving the Brazilian economy. Thus, the competitive advantages and productive increases achieved by the production of Brazilian soybean, in general, have in export logistics the main obstacle due to being costly and inefficient, and these advantages disappear due to bottlenecks and logistical deficiencies in the transport (Caixeta Filho and Péra, 2018; Cruz et al., 2009; Pontes et al., 2009) With an efficient logistics system could allow the competitiveness of Brazilian soybeans to be maintained internationally and increases the net marketing revenue of the producer and trading (Pontes et al., 2009; Rocha et al., 2015) and, even storing part of the production would reduce the incidence of these problems and help improve the competitiveness of this sector (Costa et al., 2015; Cruz et al., 2009).

3.2. Losses in pre-harvesting and harvesting of soybean

The reduction of post-harvest losses and sustainable food production will be important in the coming decades. Also, the growth of the urban population in developing countries, the growth of the middle class, the increase in per capita income generated by GDP, and food waste in developed countries, has increased the demand for food production and food insecurity, especially in the poorest countries in the world (Maranhão and Filho, 2017; Stuart, 2009). However, in the Brazilian soybean complex, is estimated that at least 6% of the national soybean production is wasted in the processes that involve the harvest. Official calculations show that 1% of losses occur in the pre-harvest period, 4% at harvest, 0.5% in short transport (from the farm to the warehouse) and 0.25% in long transport, from the warehouse to the endpoints (ports, industry) (Kussano and Batalha; 2012; Bonfim et al., 2013; APROSOJA, 2015; Caixeta-Filho and Péra, 2018).

Harvesting is the first step in the grain supply chain and a crucial operation that determines the overall quality of the crop (Kumar and Kalita, 2017). Property losses range from natural phenomena such as wind, hail, and excessive rainfall, as well as poor harvester regulation (Fernandes et al., 2018). According to EMBRAPA (2013) from the total losses, about 80 to 85% of these occur due to the action of the harvesters' cutting platform mechanisms (reel, cutting bar and snail), 12% caused by the internal mechanisms (track, separation, and cleaning) and 3% caused by natural pod dehiscence.

The beginning of the soybean harvest occurs when the grains present humidity of 13% to 15%, reaching its physiological maturity, which is considered a safe range that minimizes the mechanical damage of the grains caused in the harvester (EMBRAPA, 2011). Bauer and Gonzatti (2007) concluded that losses can be minimized when the grain is harvested with moisture levels of 14.6%, with a platform loss of 33.64 kg ha^{-1} and 44.21 kg ha $^{-1}$ in total. Lower compared to grains harvested with 11.4% moisture that showed platform loss of 52.85 kg ha^{-1} and 64.28 kg ha-1 in total. In fact, as lower the grain moisture during harvest will increase the losses on the cutting deck, on the combine and in total.

According to França-Neto and Henning (1984) and EMBRAPA (2003), soybeans when harvested with moisture content between 13% to 15%, have reduced the problems of mechanical damage and minimized losses in the harvest. Grains harvested with higher humidity at 15% they are prone to greater latent mechanical damage, not perceptible. When harvested with humidity levels below 12%, they are predisposed to immediate mechanical damage, the break.

The interaction between the time (temperature) and the moisture of the straw influences the soybean harvest, since, depending on the dew, temperature, and humidity throughout the day, the start and end times of the harvest are defined. In this sense, Holtz and dos Reis (2013) demonstrated that between 2:00 pm and 3:00 pm, there was a greater loss in the cutting platform, but with less total losses. In the night period, even after dark, increases the number of total losses and the straw moisture together with the grain temperature help to predict losses in mechanized soybean harvesting. Still, about the harvest periods Compagnon et al. (2012) observed that the greatest losses of soybeans occurred at night, in which the average was 120 kg ha^{-1}, while in the daytime the average losses were 45 kg ha^{-1} in total (water content in the grains 13.6%).

The factors that can influence the losses caused by the harvester are cutting height of the platform, speed of the reel, rotation and opening of the cylinder, and speed of displacement of the harvester. Regulation must be conducted in advance of harvest based on genetic material, the water content of the grain at the time of harvest, and speed of the combine (Souza et al., 2001; Toledo et al. 2008; Fernandes et al., 2018; Bock et al. 2020). According to Cassia et al. (2015), the adjustments in the cylinder clearance and rotor rotation optimized the loss rates in quantity and quality, maintaining the quality and reliability in the mechanized harvesting of grains destined for the production of seeds. However, to harvest in general, a study is required to evaluate the efficiency and viability of this type of regulation.

The factors related to grain losses that do not come from the mechanized harvesting process are inadequate sowing, weed occurrence, poor crop development, and pod dehiscence (Souza et al., 2001, Toledo et al., 2008). Assessing losses in mechanized soybean harvesting in Minas Gerais Chioderoli et al. (2012) concluded that weather uncertainties can cause delays that impair the harvest of grains, and losses related to harvest generate an average of 61.9 kg $ha^{-1.}$ Campos et al. (2005) found estimated losses ranging from 24 to 126 kg ha^{-1}, also in Minas Gerais.

The use of technology is essential to increase production and productivity. However, the application of the high technology available for the soybean harvest in Brazil can cause losses during the harvesting process, decreasing the productivity and the profit of the producers due to the incorrect regulation or inadequate use of this technology (Silva et al., 2013). According to Chioderoli et al. (2012), the harvester regulations and the agronomic characteristics of the crop should allow less quantitative losses to reach the maximum level of quality and greater economic sustainability of the production system. Faggion and Melara (2017) demonstrated that the total loss due to the machines was 3.19 bags per hectare (191.4 kg ha^{-1}), of which the cutting platform lost 54.55% and the internal mechanisms 45.45% of the total. Therefore, losses occur higher than the national average of approximately 120 kg ha^{-1} or 2.0 bags ha^{-1} (EMBRAPA, 2002), demonstrating that the regulation, together with operator training and the state of conservation of the harvester are important factors to minimize losses (Oliveira et al., 2014).

The adjustment of the harvester avoids losses, which are usually carried out by the operator, but gradually increase in the total lack of maintenance or when it is done partially (Schanoski et al., 2011). This report demonstrated that when partial maintenance is carried out losses reach between 180 and 240 kg ha^{-1} and in the total lack of maintenance observed losses above 240 kg ha^{-1}, with the majority of the harvesters evaluated losing 60.1 to 120.0 kg ha^{-1}, with an average of 81.2 kg ha^{-1}.

Neto and Troli (2003) concluded that the losses are independent of the brand and the harvester year, and are related to the lack of operator training to regulate them. However, the work is carried out in the period in which the fleet of agricultural implements is renewed, among them tractors and harvesters, and we currently have another scenario due to the modernization of the agricultural fleet through government subsidies.

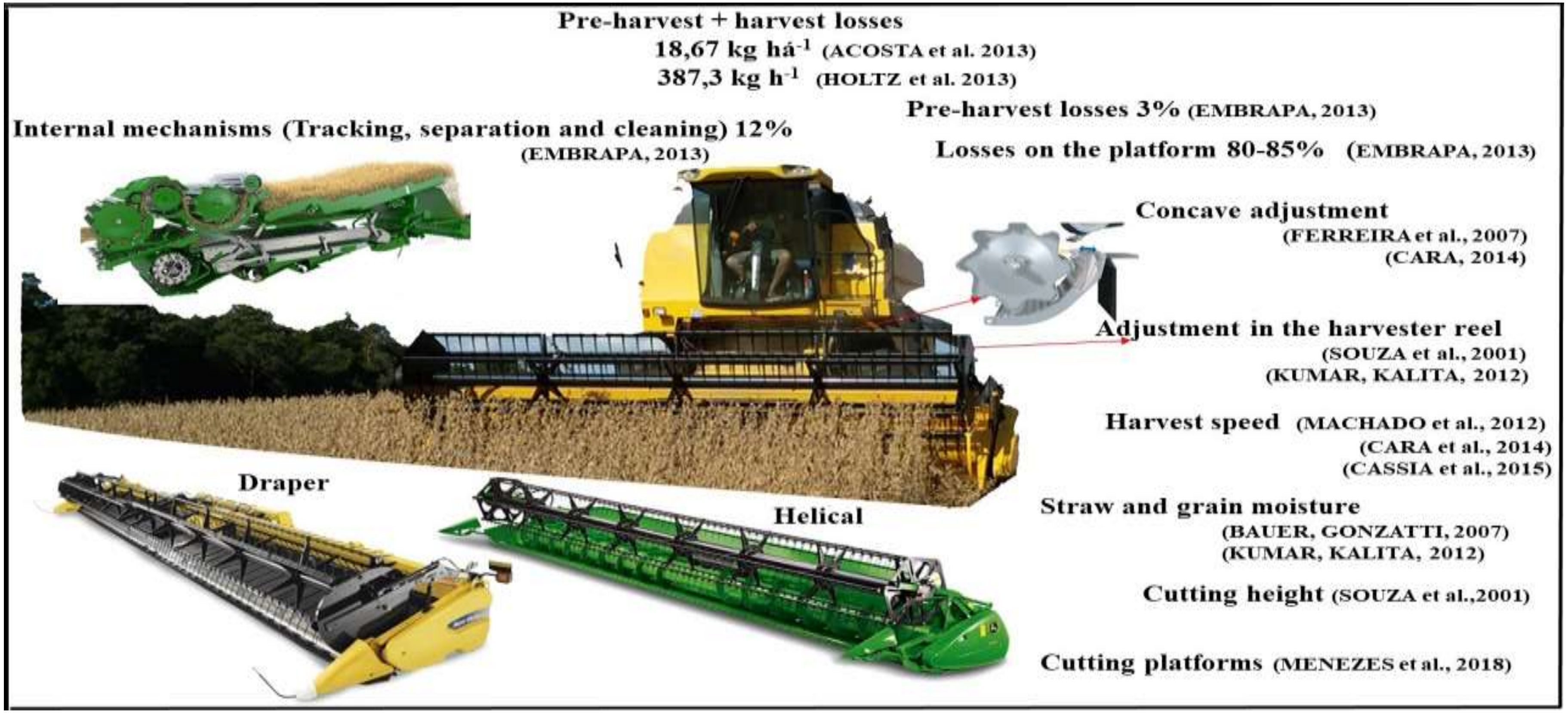
Acosta et al. (2018), using precision agriculture in Paraguay, found total harvest losses ranging from 18.67 to 88.67 kg ha^{-1}. While, Zandonadi et al. (2015) concluded that 69% of the harvesters evaluated showed an acceptable level of losses (up to 60 kg ha^{-1}), considering the harvesters that were inadequate working conditions the average total loss was 57 kg ha^{-1}, in some cases harvesters were found with losses of less than 40 kg ha^{-1} (25% of the fleet) and even with losses of less than 20 kg ha^{-1}. These data show that losses can be reduced in the soybean harvest in the Mid-North region of Mato Grosso because the maintenance and regulation of the harvesters directly impacted their reduction in the soybean harvest.

According to Machado et al. (2012), losses are correlated with the windlass rotation and the displacement speed. With a speed of 5 km h^{-1}, and a windlass rotation at 30 rpm generated average losses of 49.36 kg ha^{-1}; with a rotation of 20 rpm and 40 rpm resulted in losses of 76.76 kg ha^{-1} and 90.61 kg ha^{-1}; With a speed of 7 km h^{-1} with the rotation of the 40 rpm reel, losses of à 130 kg ha^{-1} occurred. However, at the same speed, with the spinning reel of 20 rpm, losses of 48.36 kg ha^{-1} occurred. Increasing the speed of displacement and spinning of the reel, there was an increase of 160.25% (79.8 kg ha^{-1}) in losses related to the cutting platform.

Ferreira et al. (2007) demonstrated that the harvest speed related to the hollow opening has a direct influence on the harvest losses. With the opening of 29 mm at a speed of 3 km h^{-1} losses of 65.4 kg ha^{-1} occurred. However, at 6 km h^{-1} there were losses of 40 kg ha^{-1}. While with the 39 mm at a speed of 3 km h^{-1} there was a loss of 25.8 kg ha^{-1} and at 6 km h^{-1} loss of 30 kg ha^{-1}. Cara et al. (2014) found that at a speed of 5 km h^{-1} and a 20 mm hollow opening, it enabled a reduction of 12.13 kg ha^{-1} in losses of soybeans during mechanized harvesting. Menezes et al. (2018) demonstrated that harvesters with draper platforms (conveyor belts) are more efficient, reducing losses. With speeds of 6 km h^{-1} the average total losses were 1.23 and 2.17% for the draper and helical platform. While with a speed of 8 km h^{-1} the average of total losses was 1.82 and 3.43%, respectively.

Considering the reports used to contextualize the losses of the pre-harvest and harvest, Figure 2 was created focusing on the losses that occur due to the harvester. This stage has fundamental importance to obtain a final product responsibly and for the highest rate of losses in the soy chain. According to the authors in Figure 2, the losses that occurred in the harvest due to the harvester are related to the lack of regulation and maintenance of the machines. Being these procedures that are the responsibility of the operators, who need to be trained to perform their functions correctly, reducing losses in the soybean harvest.

Figure 2. Summary schematic representation of pre-harvest and harvest losses with emphasis on harvester losses.



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3.3. Losses in the transport and storage of soybean in Brazil

The harvest of the Brazilian crop in 2019/2020 was around 122 million tons, making it the largest world producer of soybeans, ahead of the United States, which produced 96.8 million (CONAB, 2020). Kumar and Kalita (2017) report that while the demand for food from the growing population remains a concern, more than a third of food is lost or wasted in post-harvest operations. The reduction of post-harvest losses, especially in countries in development, could be a sustainable solution to increase availability, reduce pressure on natural resources, eliminate hunger, and reduce global food losses.

The critical situation in developing countries is the storage. Agricultural crop movement to the consumer causes losses including several factors, such as improper handling, inefficient installations and processing, and microorganism and insect biodegradation, therefore, it is important to understand the soy chain and find the factors in the different stages that cause product losses (Kumar and Kalita, 2017).

According to Kussano and Batalha (2012) and Caixeta Filho and Péra (2018), the conventional breakage rate (losses) used by the market is 0.25% per stretch of road transport up to 1,000 km and from 0.10 to 0.50 % above 1,000 km. However, this value varies depending on the vehicle and road conditions. The intermodal transport alternatives are not always advantageous since any transshipment operation implies product loss, which revolves around 0.20% by volume. While during the cleaning and drying process of grains, physical losses of about 0.10 to 2.03% by volume may also occur. Therefore, the greater the number of handling and transshipments, the greater the rate of loss.

The main modal used to transport soy is the road, responsible for 80% of all transport. However, the concentration of the flow of soybeans, depending on their characteristics, should be in the rail and waterway modes. The most suitable for the long-distance displacement of loads with large volumes and low added value. Also the rail and waterway modals, in addition to having a much lower cost per kilometer than that charged by the road modal, emits lower rates of polluting gases in the atmosphere (SILVA and MARUJO, 2012; Souza and Uchôa, 2029; Barreto and Ribeiro, 2020).

Through a series of factors Danao et al. (2015), demonstrated that soybeans harvested with moisture content between 10.8% to 25.7%, travel time, and waiting for discharge, varying from 0.4 to 47.9 hours, together with the variation temperature during the day (hot during the day and mild at night) can affect the respiration of the grains.. Thus, the concentration of CO_2 in the grains increased proportionally in cargoes with high moisture

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content, high temperatures, the time between travel, and discharge as a function of the grains respiration, reflecting losses of dry matter of the grains.

Bonfim et al. (2013) quantified soybean weight losses due to the variation in humidity and temperature. During storage, 0.05% of the soybean weight loss occurred. During the waiting for shipment at the port (about 15 days), there is a loss of 0.3% of the gross weight of soybeans. They emphasize that the problem of storage is not related to weight loss, but the question of costs. In transport, they showed 0.5% of gross weight losses of soybeans, totaling 0.85% of losses on the gross weight of the product handled. Which could be reduced through the improvement in transport conditions and port shipment of the commodity. Still, the same authors concluded that the costs with stock, transport, and port shipment represent 15% of the final price of the product.

Grain moisture content and storage temperature affect the content of bioactive compounds in soybeans in the long-term (12 months) storage. Especially when stored at temperatures above 25°C, regardless of moisture content (Ziegler et al., 2016a). Increasing the storage time causes changes in the chemical composition of soy protein and lipids (hydroperoxides), which vary according to the storage temperature and humidity. However, cooling can be a proper alternative for the storage of grains with greater water content for short periods (Ziegler et al., 2016b).

Regarding the quality of the grain destined for the production of seeds, Zuffo et al. (2017) observed that the delay in the harvest of soybean seeds in 10 days after the physiological stage R8 impairs the vigor and germination of the seeds. Even regardless of the harvesting season, their storage time reduces the physiological quality, with an increase in the incidence of pathogens. In the same way, Tsukahara et al. (2016) concluded that in the phenological stage R8.2 the highest production values are obtained. However, after this stage, there is a decline in productivity because of the delay in the harvest. Still, the greatest accumulated losses of productivity occur with a high frequency of rainfall and with high temperature and global solar radiation.

4. Final Considerations

The logistics of the production and transport of soy in Brazil are complex due to the country extension, as well as the evolution of productivity per hectare, that is, year by year the infrastructure needed to transport and store would need to be increased to accompany production records. The losses in the pre-harvest and harvest are well clarified. However significant losses still occur due to the lack of regulation in the harvesters, which could be solved through the training of operators. Regarding losses during transport and storage in own silos or those of local companies (private or cooperatives), studies are necessary to quantify the losses, since these can be decisive for the profitability of the sector, as well as for Brazilian competitiveness in the international market.

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