CZECH UNIVERSITY OF LIFE SCIENCES

Department of Technology and Environmental Engineering

Diploma Thesis

Maintaining quality parameters of agricultural grains during postharvest treatment and storage period

Thesis Supervisor: Ing. Jiří Bradna, Ph.D.
Author: Mehdi Layegh, MSc.

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Faculty of Engineering

DIPLOMA THESIS ASSIGNMENT

Mehdi Layegh, MSc.

Technology and Environmental Engineering

Thesis title

Maintaining quality parameters of agricultural grains during post-harvest treatment and storage period

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Objectives of thesis

Storage of agriculture grainy materials with minimal post-harvest treatment, it means with higher humidity than is expected for long term storage and larger amount of undesirable impurities in stored material, requires to create microclimate in storage area that significantly slows down all biological, physical and chemical processes taking place in the stored raw material. The aim of the work is to propose measures to create suitable conditions for post-harvest treatment and subsequent storage, which in a short period of time will adjust the grainy material to acceptable quality parameters that allow their long-term storage.

Methodology

The diploma thesis is based on the performed literary analysis and the student's own conclusions in evaluating the possibilities of maintaining the quality of food grainy materials during long-term storage. The practical part of the thesis will include an assessment of the impact of individual technologies used in post-harvest treatment on the quality of chosen grainy material and technical and economic comparison.

The diploma thesis will consist of the following parts:

1. Introduction

2. Aim of the work and methodology

3. Overview of knowledge from the literature

4. Initial conditions

5. Proposed solution and achieved results

6. Discussion and conclusions

7. References

8. Attachments

The proposed extent of the thesis

50-60

Keywords

quality of grain, post-harvest treatment, microclimate, storage period

Recommended information sources

DENDY, D A V. – DOBRASZCZYK, B J. *Cereals and cereal products : chemistry and technology.* Gaithersburg, Md.: Aspen Publishers, 2001. ISBN 0834217678.

FELLOWS, P. *Food processing technology : principles and practice.* Cambridge: CRC, 2002. ISBN 1-85573-533-4.

JONES, H D. – C.A.B. INTERNATIONAL, ISSUING BODY. *Biotechnology of major cereals.* Wallingford, Oxfordshire, UK: CABI, 2016. ISBN 9781780645209.

KENT, N L. – EVERS, A D. *Technology of cereals : an introduction for students of food science and agriculture.* Oxford [England] ; New York: Pergamon, 1994. ISBN 0080408338.

MALEŘ, J. *Posklizňové ošetřování zrnin.* Praha: Institut výchovy a vzdělávání ministerstva zemědělství České republiky, 1996. ISBN 80-7105-112-8.

MALEŘ, J. *Zpracování obilovin.* Praha: Institut výchovy a vzdělávání Ministerstva zemědělství ČR, 1994. ISBN 80-7105-073-3.

SKALICKÝ, J., P. KROUPA, J. BRADNA a L. PASTORKOVÁ. Ošetřování a skladování zrnin ve věžových zásobnících a halových skladech: metodická příručka. Praha: Výzkumný ústav zemědělské techniky, 2008, 80 s. ISBN 978-80-86884-38-7.

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The Diploma Thesis Supervisor

Ing. Jiří Bradna, Ph.D.

Supervising department

Department of Technological Equipment of Buildings

Prague on 25. 03. 2022

DIPLOMA THESIS AUTHOR'S DECLARATION

I hereby declare that I have independently elaborated the diploma/final thesis with the topic of:

Maintaining quality parameters of agricultural grains during postharvest treatment and storage period, and that I have cited all the information sources that I used in the thesis and that are also listed at the end of the thesis in the list of used information sources. I am aware that my diploma/final thesis is subject to Act No. 121/2000 Coll., on copyright, on rights related to copyright and on amendment of some acts, as amended by later regulations, particularly the provisions of Section 35(3) of the act on the use of the thesis. I am aware that by submitting the diploma/final thesis I agree with its publication under Act No. 111/1998 Coll., on universities and on the change and amendments of some acts, as amended, regardless of the result of its defense. With my own signature, I also declare that the electronic version is identical to the printed version and the data stated in the thesis has been processed in relation to the GDPR.

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Mehdi Layegh

ACKNOWLEDGEMENTS

ABSTRACT

All around the globe, the loss of grain during the storage phase constitutes a significant element in postharvest losses, representing a primary cause of food insecurity for smallholder farmers. Small reductions in grain damage caused by transportation of the grains are significant. Since grain undergoes multiple handling steps during postharvest processing, any accumulated damage can be substantial. Therefore, minimizing damage at each stage contributes to a higher overall yield and ultimately increases grain market production. The diploma thesis consists of two parts. The first part is extracted from professional literature and focuses briefly on the description of the postharvest line. The second part, which is experimental, reveals that grain losses on two common types of conveyors which were measured in the chosen farm in the middle part of the Czech Republic. This diploma thesis examines how grain quality is affected after harvest, focusing on damage to the outer layer. Furthermore, it is aimed to assess grain damage caused by multiple common types of conveyors, the preferred methods for horizontal grain movement in grain processing facilities. Generally, these conveyors are known for minimizing damage to grain kernels during reception, treatment, and storage. The amount of fragments and total mechanical damage to the grain with the belt conveyor was almost 4-5 times smaller than chain conveyor and this numbers can raise when it is working below the nominal efficiency and full capacity of chain conveyor. It is highly recommended to use a belt conveyor where it is possible in postharvest line, due to the minimum damage to the grains, and simplicity of this type of conveyor.

KEYWORDS: Quality of grain, postharvest treatment, transporting routes, storage losses

Contents

1. Introduction

Worldwide, food crops are cultivated and consumed throughout the year, both seasonally and continuously. Nevertheless, smallholder farmers in underdeveloped nations face limitations in agricultural mechanization. As a result, nearly all agricultural activities, including pre-harvest and postharvest operations such as drying, dehulling, shelling, winnowing, sorting, transportation, and storage, are carried out manually. Under these circumstances, it has been estimated that quantitative losses of up to 15% occur in the field postharvest, 13–20% during processing, and 15–25% during storage (Abass et al. 2014). This results in a significant decline in food quality, and an increase in food loss and food insecurity among farm households. Studies indicate that the annual value of waste and food spoilage in developing nations with nearly 65% occurring during the stages of production, processing, and postharvest (Pedrick et al. 2012).

The grain loss during the storage phase is considered a significant element in postharvest losses, representing a primary cause of food insecurity for smallholder farmers in underdeveloped nations. Traditional storage methods employed by smallholder farmers in developing countries typically involve the use of woven bags or cribs. However, these methods have proven ineffective in addressing pre-existing mold and insect issues within the stored grain. Some farmers resort to incorporating various chemicals to enhance the storability of the grain. While hermetic storage systems present a viable alternative by minimizing storage losses without relying on chemicals, challenges arise. Consequently, an ideal grain storage system for smallholder farmers should possess hermetic sealing capabilities, mechanical durability, and cost-effectiveness compared to conventional options. Such a system would contribute to reducing grain storage losses, preserving grain quality, and ultimately mitigating food insecurity for smallholder farmers in developing countries (Manandhar et al. 2018). Concentrated studies on storage practices applicable to staple crops like maize and rice, as well as legumes such as cowpeas and beans commonly cultivated by smallholder farmers globally. The research searched various postharvest losses within the grain supply chain, exploring the impact of factors such as insect activities, mold growth, mycotoxins, moisture, temperature, and social considerations on the choice of grain storage systems. The investigation examines several grain

storage methods, including traditional structures and handling systems, secondly the use of chemicals in conjunction with other storage structures, or hermetic metal silos with hermetic bagging technology, self-built silos and at the end also on-farm and community-based storage structures. The review proposes desirable qualities for storage structures based on the assessed systems, aiming to effectively mitigate postharvest grain storage losses (Manandhar et al. 2018).

Scientific studies define the decline in both the quantity and quality of food production during the time from harvest to consumption as postharvest loss. These losses entail a reduction in the quality of a product, impacting its nutrient or caloric composition, acceptability, and edibility. Such losses are predominantly observed in developed countries (Kader, 2002). Conversely, losses associated with the decrease in the quantity of a product are termed quantitative losses. These losses in quantity are typically prevalent in developing countries (Kitinoja et al. 1999). A recent report from the FAO highlights a global disparity in the patterns of food loss and waste between high-income regions and low-income regions. The findings reveal that in high-income regions, greater volumes of food are lost and wasted in the downstream phases of the food chain. In contrast, in low-income regions, more food is wasted in the upstream phases of the food chain (FAO, 2013). Postharvest grain losses encompass all the reductions in grain from the point of harvesting until its use for consumption. Whether these losses involve a decrease in quantity or quality, they both contribute significantly to the diminished value of the product. Quantity losses arise from spillage, scattering, direct pest and bird infestation, mycotoxins, or mechanical breakages. On the other hand, qualitative losses primarily result from mold infestation, mycotoxins, and mechanical breakages (Manandhar et al. 2018). In less developed nations, grains are commonly stored for extended periods after harvest, surpassing the duration of other postharvest stages. The challenge lies in insufficient monitoring of the grain during storage. Effective reduction of grain loss primarily hinges on maintaining appropriate storage conditions. Factors such as physical, biological, and socioeconomic elements play a pivotal role in storage losses. Physical factors, encompassing oxygen, moisture, relative humidity, and temperature, significantly influence the storability of grain by affecting conditions conducive to insect multiplication and mold growth throughout the storage period (Chigoverah et al. 2016). Under optimal temperature and moisture conditions, coupled with the presence of grain, mold spores adhere to the surface and

thrive. Additionally, temperature gradients encourage the accumulation of moisture at specific points within the storage system, creating ideal conditions for the growth of mold. For cereals stored in silos or warehouses, the temperature at the center of the grain volume remains relatively constant, like the temperature at harvest. In contrast, the grain in contact with the storage walls experiences temperature fluctuations based on the external air temperatures. Consequently, when high-moisture content grain is stored with high relative humidity, as external temperatures decrease, the walls cool more rapidly, leading to condensation and the formation of damp areas that promote mold growth. Increased moisture and oxygen availability elevate the grain's respiration rate, generating heat, carbon dioxide, and enzymes. These factors contribute to the breakdown of starch, proteins, and lipids in the grain. Insects, engaged in metabolic activities, consume available oxygen, raising carbon dioxide concentrations within hermetic storage systems through respiration (Navarro, 2006), (Xihong et al. 1998).

2. Objectives

Storing unprocessed grains with higher moisture content and more impurities than ideal for long-term storage period requires creating a specific environment within the storage area. This environment needs to significantly slow down all the natural biological, physical and chemical changes that happen to the grain while it's in storage. Grain quality, especially its outer condition, is affected by what happens after harvest. In general, handling grain can cause a lot of damage. This includes cleaning the grain and how it's handled commonly with a conveyor or an elevator.

This diploma thesis aims to specifically measure how much mechanical damage occurs to grains during transport using different types of conveyors in chosen postharvest line equipped with chain and belt conveyors which are the most used methods for moving grain in Czech agricultural postharvest systems. The focus is on recommending the best way to transport grain within storage systems. By analyzing different conveyor types and their features, the ideal conveyor system to minimize grain damage will be identified and the possibility to replace the old transport technology will be arranged theoretically.

In this framework, the research will be based on the following steps:

Literature Review: A comprehensive review of the existing literature on the impacts of different types of conveyors and their effects on the grain.

Data Collection: Collecting and comparing data on the damages caused by conveyors to the grains during grain transportation in chosen postharvest line.

Sampling: To measure grain damage, samples were collected at two points: before entering the conveyors and after passing through it. This process followed the ČSN ISO 950 standard for sampling. The quality requirements for the grain itself were based on separate Czech standards like ČSN 46 1100-2, and ČSN 46 1100-5, etc. And laboratory tests were done in the accredited laboratory.

Analysis: Comparison of the amount of damage between conveyors with proposal of the suitable conveyor for replacement in the technology.

3. Literature Review

This section summarizes key ideas and established principles from relevant research and publications by other respected groups.

3.1 Food Grains Composition and Cultivation of cereals

The Czech Republic cultivates a variety of grains, including wheat and barley. Other grains like corn, millet, and buckwheat are also grown in this country. This diploma thesis focuses specifically on food varieties of wheat, the most significant grain crop. Understanding the composition of cereal grains is crucial throughout the entire grain's journey. From harvest and transport to storage, processing, and finally pricing, knowing the grain's makeup informs every step. This importance is developed because cereal grains are composed of various cell types, each with its own unique nutrient content, size, and shape. Overall, the grain contains 12-14% moisture, 8-16% protein, 1-5% fat, and a small amount of minerals and vitamins. The Chemical compositions and energy values of selected cereal grains are shown in Table 3.1 (MARTÍNEK et al. 2012).

Grain	Carbohydrate (%)	Protein (%)	Lipid (%)	Total dietary fiber (%)	Sugar (%)	Energy (kcal/100 g)
Wheat hard white	75.90	11.31	1.71	12.2	0.41	342
Wheat soft white	75.36	10.69	1.99	12.7	0.41	340
Durum heat	71.13	13.68	2.47	–	–	339
Maize, yellow	74.26	9.42	4.74	7.3	0.64	365
Brown Rice	76.17	7.50	2.68	3.4	–	362
Barley	77.72	9.91	1.16	15.6	0.80	352
Sorghum	72.09	10.62	3.46	6.7	2.53	329
Oats	66.27	16.89	6.90	10.6	–	389
Millet	72.85	11.02	4.22	8.5	–	378
Rye	75.86	10.34	1.63	15.1	0.98	338
Triticale	72.13	13.05	2.09	–	–	336

Table 3.1: Chemical compositions and energy values of some grains (MARTÍNEK et al. 2012)

A wheat grain has a remarkable structure, cramming in all the parts needed to create a new wheat plant in a tiny package. Fig. 3.1 presents key components of a grain.
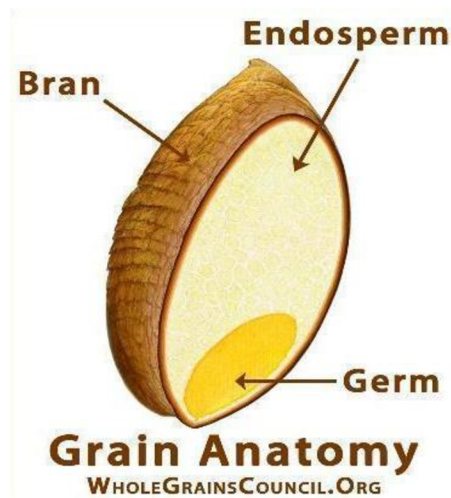

Fig. 3.1: Grain anatomy (Wholegrainscouncil.org, 2022)

Bran: The outermost layer, made up of several sub-layers rich in fiber, vitamins, and minerals. It acts as a protective coat for the inner parts of the grain.

Endosperm: The largest part of the wheat grain, consisting mainly of starch (for energy) and protein. This is the part that gets milled into flour.

Germ: The embryo of the wheat plant, containing vitamins, minerals, and healthy fats. It's located at the bottom tip of the grain.

These parts differ mainly in their chemical composition (Table 3.2), but each part also fulfills its function in the life of the grain, either as protection of the kernel or supply of nutrients to the sprout when the root is inserted (MARTÍNEK et al. 2012).

Parts of Grain	Mass ratio of the grain part	Protein (%)	Scratch (%)	Sugar (%)	Fiber (%)	Pentosans (%)	Fats (%)	Ash (%)
Whole Grain	100	16.1	63.1	4.3	2.8	8.1	2.2	2.2
Endosperm	81.6	12.9	78.8	3.5	0.2	2.7	0.7	0.5
Germ	3.2	37.6	-	25.1	2.5	9.7	15	0.3
Bran	15.5	28.8	-	4.2	16.2	35.7	7.8	10.5

Table 3.2: Chemical composition of wheat grain (MARTÍNEK et al. 2012)

The Czech Republic is a major producer of cereals, cultivating both winter and spring varieties. Winter wheat dominates, sown during the transitional months of September

and October. The following spring and summer witness flowering and fruiting, with harvest typically occurring in mid-July. However, due to their impact on soil quality, consecutive cereal plantings are not recommended. Spring wheat, typically sown in March, serves as a supplementary crop to winter wheat. Both winter and spring wheat benefit from similar pre-crops, such as root vegetables, oilseeds, and legumes. Additionally, other wheat types like durum wheat and spelt are also cultivated (cit.vfu.cz, 2022).

Data from the Czech Statistical Office (CZSO) indicates that the total cereal harvest in 2021 reached 8,227.1 thousand tones. This translates to an average yield of 6.11 tons per hectare. Compared to the 2020 harvest, this represents a 1.2% increase. In terms of quality indicators for food wheat, only 58% of samples meet the evaluated parameters, according to completed analyses. In 2020 and 2019, these values were 55% and 63%. The most common limiting parameters were protein content and sedimentation value. On the other hand, analyses of the 2021 harvest of malting barley showed a quite satisfactory quality. However, production can be considered below average. Compared to 2020, barley grain has higher values of overrun on a 2.5 mm sieve, i.e. the grain is larger. At the same time, it has a favorable content of nitrogenous substances (eagri.cz, 2021).

3.2 Microclimate in Storage Facilities

Local weather and agricultural limitations create a seasonal supply of grains for food processing, while food industries demand a constant flow of raw materials (Laszlo et al. 2009). This mismatch creates challenges for logistics and necessitates sophisticated storage facilities. Maintaining the quality of stored grain throughout the year is the primary concern in agricultural storage. Environmental control plays a crucial role in achieving this. By lowering temperature and moisture content within the storage unit, we minimize the biological activity of potential contaminants like insects, mites, fungi, and their toxins (Jia et al. 2001). Postharvest treatments like thorough cleaning, sorting, and optimized transportation routes further ensure grain quality (Fourar-Belaifa et al. 2011).

Unlike inert materials, stored grains are living and respond to their storage environment, called the microclimate. Improper storage conditions, a combination of physical, chemical, and biological factors, can lead to their deterioration (Cetiner et al.

2017). Undried grains, through respiration, generate heat, moisture, and carbon dioxide. These factors, along with storage temperature and moisture content, significantly influence the activity of organisms that can decompose the grain (Capouchová et al. 2009).

Stored grain essentially forms a miniature ecosystem where the grain and other organisms interact, all impacted by the surrounding conditions (Polišenská et al. 2010). By understanding grain behavior in storage, implementing safety guidelines, practicing proper facility management, and incorporating quality control procedures, we can minimize quality loss (Kibar, 2015).

Modern grain storage utilizes various options, including silos (tall towers), warehouses (storage halls), and smaller units like boxed pallets and large bags for seeds or final consumption. Metal silos reign supreme in this category due to their exceptional long-term protection for stored grains. These versatile metal structures come in diverse shapes, primarily cylindrical or rectangular, and offer capacities ranging from tens to thousands of tons (Skalický et al. 2008).

Metal silos, compared to storage halls, face a greater challenge with moisture condensation. This is because temperature fluctuations within the silo, including hot spots, are harder to address with sufficient aeration, especially in taller structures (Hammami et al. 2017). Storage halls offer advantages in terms of both volume and aeration. Their lower grain piles and flexible duct design allow for better air circulation. Mathematical models can be used to predict temperature and moisture distribution within stored grain (Laszlo et al. 2009; Casada, 2000; Jia et al., 2001). These models can then be used to strategically place sensors for early detection of temperature spikes in stored grain.

Several factors influence temperature distribution within a grain storage facility. The first set of factors relates to external conditions: ambient air temperature, air movement, solar radiation hitting the structure, and the warehouse's location relative to prevailing winds. The second set of factors pertains to the building itself: its design, size, and construction. While convective heat transfer is important within the storage unit, we shouldn't neglect the significant impact of ambient temperature and humidity on the bottom layer of the silo, particularly those factors not directly accounted for in silo design (Yang et al. 2002).

A storage hall could maintain its internal climate despite external weather conditions to address potential climate-related challenges, the facility was equipped with a robust aeration system featuring floor ducts. The study's objective was to assess temperature fluctuations within the storage area and their correlation with outdoor climatic conditions using statistical methods (Bradna et al. 2018).

Maintaining consistent storage temperature is crucial for preserving the quality of malting barley. Ideally, temperatures should stay within a narrow range, typically between 5-10°C. To prevent spoilage, keep storage temperatures below 25°C for extended periods by promptly airing out the commodity after harvest. To achieve this, prompt aeration after harvest is essential. Monitoring data reveals a strong correlation between daytime temperature fluctuations in the barley and the amount of electricity used for aeration. This suggests that aeration plays a significant role in managing temperature and maintaining optimal storage conditions. The study also revealed a long-term connection between the average daily temperature inside the barley and the average daily outside temperature. However, this link was significantly weaker compared to traditional tower silos. This can be attributed to three factors: the insulating properties of the storage unit's outer shell, the implemented aeration system, and the sheer volume of the stored barley itself. Interestingly, the data suggests this outside temperature influence is very weak during the first four months after harvest, a period when active aeration plays a crucial role in stabilizing the stored barley (Bradna et al. 2018).

A year-long study monitored temperature variations within a barley storage hall over two storage seasons. The researchers observed a rise in temperature at a depth of 2.1 meters within the grain layer specifically from July to September. This increase was significant compared to both outdoor temperatures and temperatures measured throughout the rest of the storage period. This rise in temperature likely stems from two contributing factors: heat generated by the respiration of the grains themselves, and the cumulative effect of daytime heating and long periods of sunlight. The gradual rise in temperature from July to the dry season's start (October) suggests this extended period as the culprit behind the September peak. To prevent excessive heat buildup and safeguard grain quality, the storage hall might benefit from aeration during these months. This helps prevent infestations from insects and fungi, and the mycotoxins they produce (Bradna et al. 2018).

3.3 Conveyors Used in the Food Industry

3.3.1 Belt Conveyors

There are many different types of belt conveyors, each designed for a specific purpose. Belt conveyors are one of the most versatile and widely used pieces of material handling equipment. They are used to transport a wide variety of materials, from bulk solids to finished goods. In grain storage systems, belt conveyors are the gentlest way to move grain horizontally (Fig. 3.2 and 3.3).
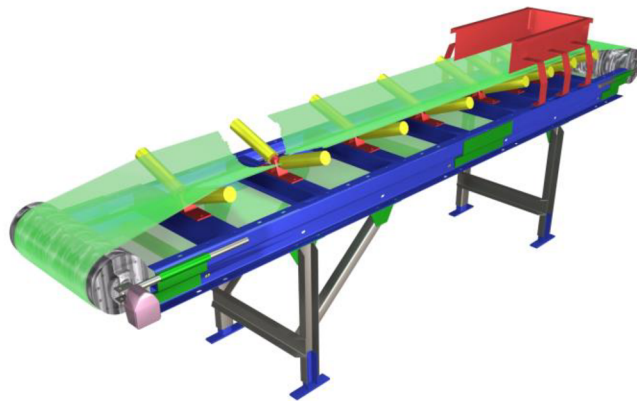

Fig. 3.2: Light-Duty Belt Conveyor (Jansen & Heuning www.jh.nl, 2023)

Fig. 3.3: Heavy-Duty Belt Conveyor (Jansen & Heuning www.jh.nl, 2023)

Belt conveyors serve as pivotal components within industrial processing systems, facilitating the seamless transfer of materials while preserving product integrity and specified attributes. However, within the food-processing sector, concerns regarding product hygiene arise, highlighting the importance of well-designed and well-maintained conveyor systems to mitigate potential hazards. The necessity for heightened hygiene levels not only fulfills public obligations but also serves as a strategic measure to minimize waste, recalls, and cleaning expenditures, particularly amid rising labor costs and water scarcity. The concept of "cleanability" has emerged as a central tenet, emphasizing the critical role of conveyors in modern processing environments (Kold et al. 2016).

The design of conveyor systems, particularly in the realm of food hygiene, necessitates adherence to specific principles. These include the elimination of sharp corners and edges to prevent product accumulation, ensuring unimpeded product flow, and minimizing horizontal surfaces to facilitate efficient water runoff. Compliance with EU Machine Directive regulations is mandatory, particularly concerning product-contact surfaces designed to meet stringent hygiene standards. Hygienic considerations extend to conveyor belts and associated components, which directly interact with food products. Three primary belt technologies - ply/fabric belts, homogeneous belts, and modular belts - vie for attention in terms of food hygiene. Each technology presents unique advantages and considerations, demanding tailored approaches to design and maintenance. Fabric-reinforced conveyor belts, or ply belts, offer versatility but are susceptible to wear, tear, and soil trapping, necessitating preventive measures such as edge sealing and careful fabrication. Homogeneous flat belts, devoid of reinforcing fabric layers, mitigate fabric-related issues and facilitate seamless cleaning through welded seams. Positive-drive homogeneous belts, featuring tooth engagement with sprockets, eliminate friction rollers and support effective cleaning and disinfection. Modular conveyor belts, comprising interconnected modules, provide high strength and resistance to impacts but require meticulous cleaning and adherence to manufacturer recommendations. Wire and metal belts, characterized by open mesh constructions, enable thorough disinfection and positive drive through toothed sprockets. Profiled conveyor belts, including round and V-profile variants, offer a strong grip with minimal contact and require tailored cleaning approaches based on environmental factors.

Food-grade conveyor belts must comply with food safety regulations, with blue belts preferred for their detectability and certification requirements under regulations like EU 10/2011. Textured belt surfaces demand specialized cleaning protocols, while belts with features like guides or flights necessitate careful attention during cleaning procedures. In conclusion, achieving optimal hygiene standards in conveyor systems necessitates meticulous attention to design, materials, and maintenance practices. A nuanced understanding of various conveyor technologies and their specific hygiene challenges is indispensable for informed decision-making in the ever-evolving landscape of food processing, aligning with the imperative for enhanced hygiene amid evolving industry demands and global concerns (Kold et al. 2016).

3.3.2 Screw conveyors

Known as auger conveyors, are another essential piece of equipment used extensively in grain storage facilities. They utilize a rotating helical screw that moves material within a trough. Screw conveyors efficiently transport bulk materials like grain horizontally, vertically, or even at an incline (Fig. 3.4).
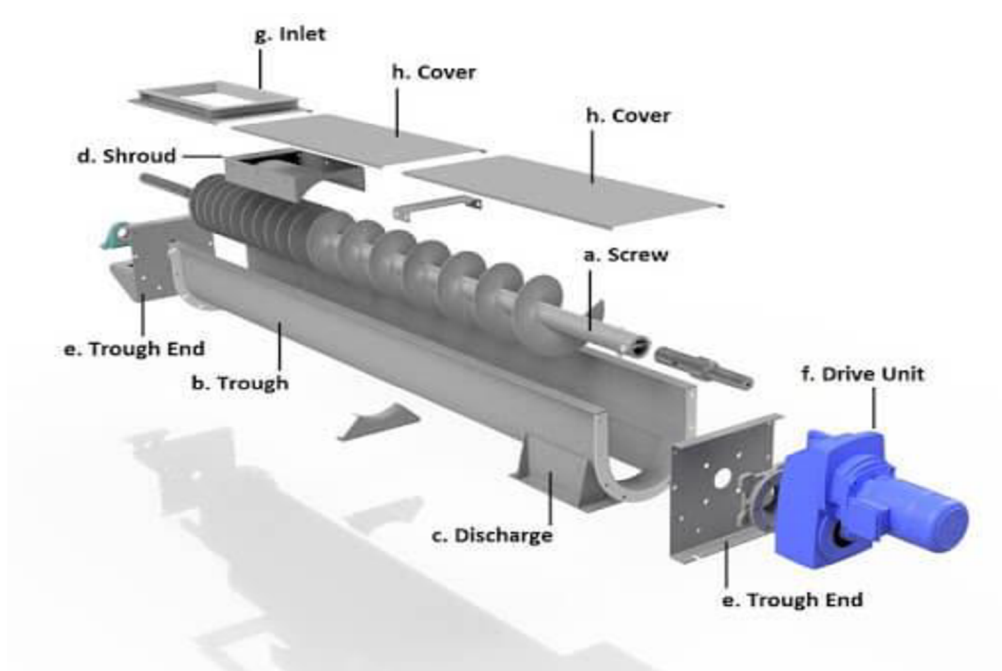

Fig. 3.4: Screw Conveyor (Jansen & Heuning www.jh.nl, 2023)

Due to simple construction and high reliability of screw conveyors, they are commonly applied in various agricultural machines. Despite their broad application, there is scarce literature concerning the influence of their main exploitation and construction

factors on the efficiency, energy consumption, and damage of relocated grain during the relocation process. Considering the above-mentioned fact, this paper attempts at a synthesis of the accessible research on these facilities, explaining the reciprocal relationships among the mentioned factors and geometrical and kinematical parameters of the screw conveyor (Dreszer et al. 2007).

The versatility of the screw conveyor makes them ideal for various grain handling operations within a storage facility. Screw conveyors have some advantages in grain storage like controlled movement, they provide a gentle and controlled movement of grain, minimizing grain damage during transfer. They excel at efficiently conveying grain over short to medium distances within the storage structure. Certain screw conveyor designs allow for controlled feeding of grain at specific rates, crucial for loading processes. There are different types of conveyors for Grain Storage. U-Trough Screw Conveyors are the most common type, featuring a U-shaped trough for maximum capacity (Fig. 3.4). Tubular Screw Conveyors are ideal for situations where dust control or preventing grain spillovers is necessary. Flexible screw conveyors offer maneuverability for reaching tight spaces during grain bin loading/unloading. Many studies have investigated the efficiency of screw conveyors, employing various research methods (Römer et al. 1955; Antoniak, 1964; Fąfara, 1967; Brusewitz et al. 1969; Janczin, 1969; Borisow, 1972, Glozman et al. 1978; Klimowski, 1978; Smereczyński et al. 1978; Dreszer 1981, 1984). These studies aimed to identify the key factors affecting efficiency, going beyond limitations imposed by available research techniques or the materials tested (grain, straw, dough, etc.). This focus on a wider range of variables led to the development of diverse research methods and approaches. However, the resulting efficiency formulas often incorporated experimentally or theoretically derived coefficients, which can limit the comparability of findings across different studies (Antoniak, 1964, Goŝdziecki et al. 1975; Dmitrewski 1978).

Mechanical damages are occurring during the process of relocation with screw conveyors. Despite their apparent simplicity and reliability, screw conveyors can raise concerns when handling delicate materials like grain. The relocation process exposes the grain to both static and dynamic forces, which can cause damage on both microscopic and macroscopic scales. This damage lowers the grain's biological value and market worth. The main culprits behind this damage during grain transport with

screw conveyors are Cutting, friction, and crushing. Sharp edges at the inlet, where the wall and screw flight meet, can sever the grain kernels. Contact with the conveyor's moving parts (internal friction) and the housing (external friction) can damage the grain. Grains can be crushed between the screw flight and the conveyor wall. In addition to the feeding method (parallel or submerged), the design of the inlet geometry, specifically the shape of the wall and screw flight edges, can significantly contribute to grain damage (see Fig. 3.5) (Dreszer et al. 2007).
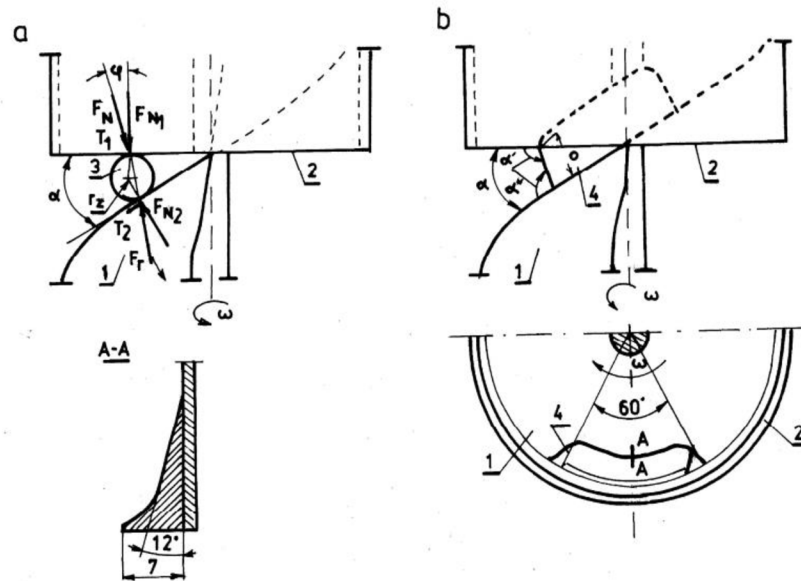
Fig. 3.5: Scheme of work of a screw coil at the inlet to the working passage acc. to: a) the commonly used pattern, b) pattern with an insert eliminating cutting forces, 1 – screw coil, 2 – wall edge, 3 – grain, 4 – insert. (Rademacher, 1981)

The clearance between wall and screw coil (2) is another important factor affecting the number of damages in the relocated grain (Fig. 3.6) (Dreszer et al. 2007).
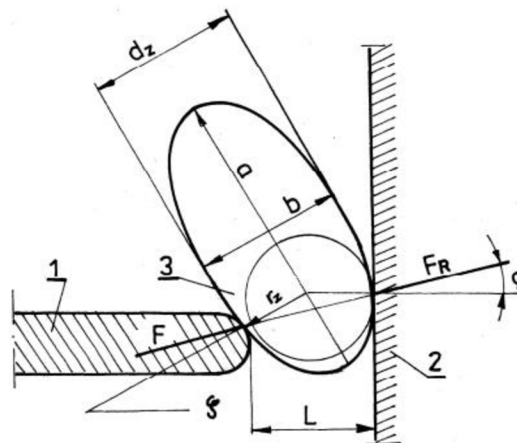

Fig. 3.6: Scheme of work of a screw coil at the inlet to the working passage (Rademacher, 1981)

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Some factors can decrease the mechanical damage to the gains in the screw conveyors. Studies found that rice with higher moisture content (14%) suffers less damage than drier rice (8%) when handled. Furthermore, increasing the screw flight rotating speed from 100 to 500 rpm causes a tremendous increase in the grain's damage. The results also mentioned that when the screw clearance increased from 6 to 15 mm, the damage significantly dropped. Based on the results which were obtained in Zareiforoush's study, to decrease the extent of damage in handling with screw conveyors, the lower moisture contents for the grains, the lower screw clearances and the higher speeds for the rotating flight should be avoided. Based on the results obtained in this study and comparing the results with the reports of rice grains damage in combine harvesters, it can be concluded that the extent of grain damage in the handling process with screw conveyor is remarkably lower than that of in the combine cylinder. (Zareiforoush et al. 2010).

3.3.3 Inclined screw conveyors

Inclined screw conveyors as a variation of the standard screw conveyors offer several advantages for specific applications in grain storage and other industries (Fig. 3.7).
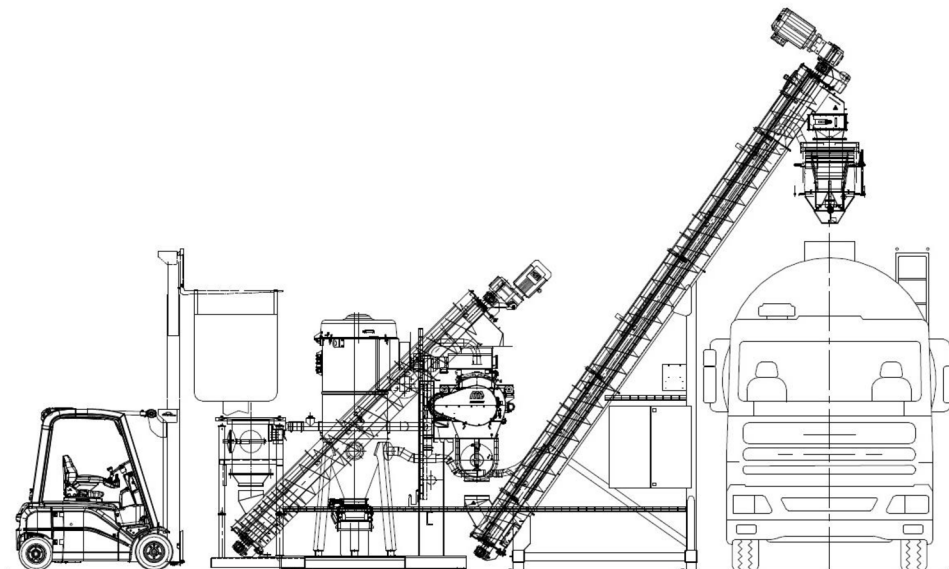

Fig. 3.7: Inclined screw conveyors (Jansen & Heuning www.jh.nl, 2023)

Inclined screw conveyors handle both horizontal and vertical transportation in one unit, saving space and simplifying your setup compared to needing separate horizontal and vertical conveyors. They are efficient for short inclines and for conveying grain

up inclines, inclined screw conveyors provide a cost-effective solution. Like regular screw conveyors, they offer almost gentle and controlled movement of grain, minimizing grain damage during transfer. Inclined screw conveyors can be built with an enclosed trough, ideal for dust control and preventing grain spillage in your storage facility. Factors like material you will be conveying, inclination angle, length, diameter of the conveyor, and required features like enclosed trough, metering capabilities should be considered to select an inclined screw conveyor.

Many researchers have investigated how factors like machine settings, weather, and the rice itself affect how much grain is lost during processing, from harvest all the way to milling (Andrews et al. 1993; Cnossen et al. 2003; Iguaz et al. 2006; Peter et al. 2000; Roy et al., 2007; Siebenmorgen et al. 1998; Siebenmorgen et al. 2009; Wiset et al. 2001). Turning paddy rice into white rice involves several steps, from harvest to final processing. These steps include threshing, handling, removing the husks, milling, and polishing. If the equipment used in these steps isn't adjusted correctly, a significant amount of rice can be lost.

According to the FAO, a staggering 10% of rice in Southeast Asia is lost after harvesting due to improper handling at various stages, including cutting, moving, threshing, drying, storing, and transporting the rice (FAO, 1997).

Like screw conveyors, inclined screw conveyors have their own effect on the grains like rice damage. Investigation on the factors like moisture content, angle of the conveyor, and screw speed showed that rice with higher moisture content (14%) broke less than drier rice (8%). Also, faster screw speeds (500 rpm) caused more damage than slower speeds (100 rpm). Another factor that investigated was the angle of the conveyor which didn't affect breakage much, but it did influence how many hulls got removed from the rice. Overall, to minimize broken rice use moist rice (14%), slow down the screw speed (100 rpm), and keep the conveyor as flat as possible (10° angle) (Zareiforoush et al. 2010).

3.3.4 Chain conveyor

Chain conveyors are a family of conveyors that use an endless chain not only to transmit power, but also to carry or propel material forward (Fig. 3.8). Material is moved directly by the chain or attachments on it.
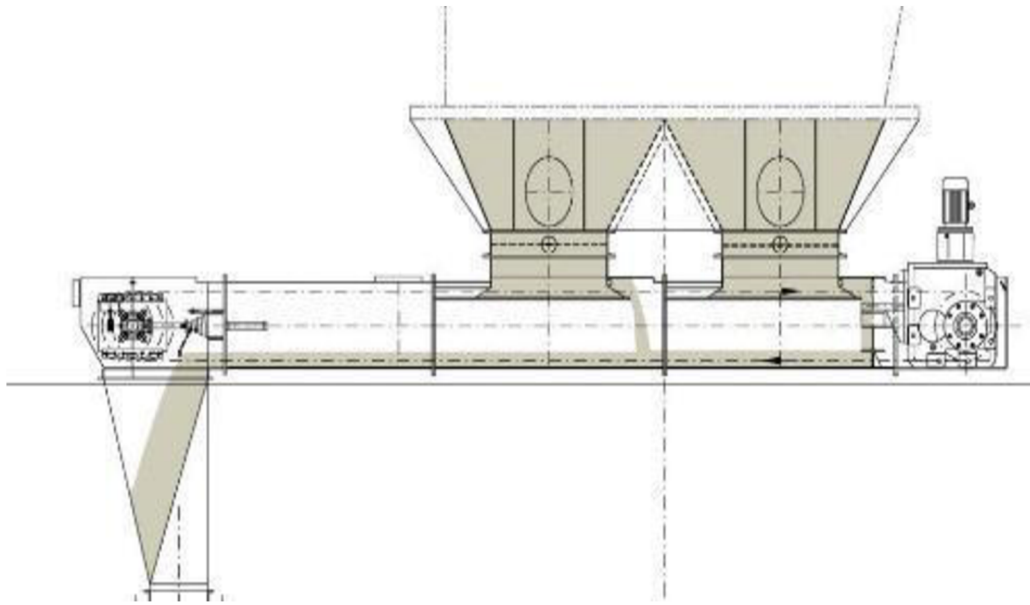
Fig. 3.8: Chain conveyor arrangement (aumund.com, 2023)

Types of chain conveyor include apron, drag, plain chain, scraper, flight, and en-masse conveyors. There's a misconception that chain conveyors are costly, require a lot of upkeep, and use excessive energy. But that's not always the case. If used correctly, they can be very reliable, even for handling difficult materials (Gunal et al. 1996).

Chain conveyors utilize an endless loop of chain driven by sprockets, typically located at the discharge end. Alternative drive configurations exist. A take-up mechanism at the opposite end maintains appropriate chain tension. Material conveyance or propulsion is achieved by the chain itself or various attachments like pans, scraper blades, or flights. Wider conveyors may employ multiple parallel chains synchronized through shared sprocket shafts. Certain chain conveyor types, such as drag, scraper, and flight conveyors, incorporate a trough structure for chain movement. Apron conveyors utilize attached pans or plates for material transport. These may include fixed skirt boards for material containment. A crucial design consideration is chain movement including rolling or sliding chains. Rolling chains offer quieter operation and lower energy consumption but necessitate clean surfaces. They are unsuitable for dirty environments and susceptible to wear and fouling. Sliding chains, with fewer moving parts, boast higher resistance to breakdowns but exhibit faster wear and require more horsepower due to increased friction. They are well-suited for dirty applications (Skocir, 2018).

Chain conveyors can handle significant loads compared to other conveyor types due to the sturdiness of the chain system. They can be adapted to various materials by using different attachments like pans, scraper blades, or flights. Wider conveyors can even utilize multiple chains for increased stability. Sliding chains are known for their resilience in harsh environments with minimal breakdowns due to the simpler design. Some chain conveyor designs, like apron conveyors, can be directly washed or submerged for easy cleaning, making them suitable for applications with hygiene requirements. Chain conveyors can be designed for horizontal, inclined, and even turning movements, offering flexibility in material handling within a single conveyor line (Kumar et al. 2023).

Chain conveyors, while generally efficient for bulk material handling, can cause damage to grains during transportation. Grains can be cracked or chipped due to impacts with the chain itself, conveyor trough (if present), or other grains during transfer points. Friction between the grain and chain/trough components can wear down the grain surface. In tight corners or under high pressure, grains can be crushed or split due to shearing forces within the bulk material (Skocir, 2018).

Factors like design of the chains, moisture contents of the grains, conveyor speed and capacity, chain tension, and conveyor inclination can affect damage severity. Sliding chains tend to cause more damage than rolling chains due to higher friction. Drier grains are more susceptible to cracking and breakage. Higher speeds and overloading can increase grain-to-grain and grain-to-component contact, leading to more damage. Improper tension can cause the chain to sag and impact the grain bed more severely. Steeper inclines can lead to the grain cascading down, causing more collisions and potential damage. By understanding these factors like selecting the right chain type, maintaining optimal chain tension, monitoring grain moisture content, and implementing preventive measures, chain conveyor systems can be optimized to minimize grain damage during transportation (Chen et al. 2020)

3.3.5 Bucket Elevator

The bucket elevator (Fig. 3.9) is one of the few conveyors designed for the primary purpose of elevating material (Fruchtbaum, 1988).
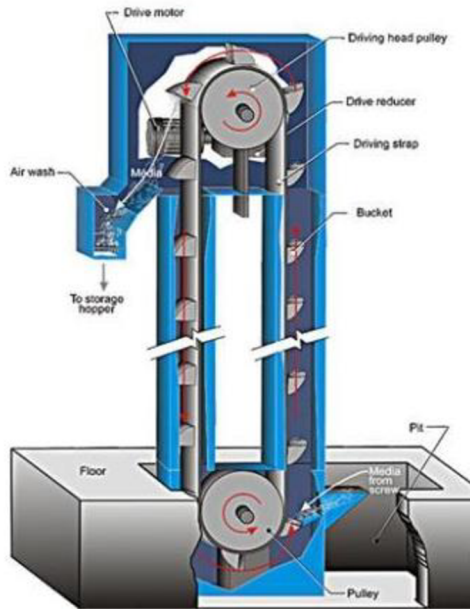
Fig. 3.9: Bucket elevator (istsurface.com, 2023)

Bucket elevators are a perfect choice for vertically lifting a wide variety of materials, from free-flowing grains to chunky fertilizers. However, like any machine, they have their own set of pros and cons. Bucket elevators can handle a vast array of materials with varying characteristics. From light and fine powders to heavy and abrasive aggregates, they can be adapted with different materials and design tweaks. They offer flexibility in terms of capacity, height, and speed. This modularity allows for easy integration into existing processes or designing new facilities with optimal material flow. Generally, bucket elevators are considered a budget-friendly solution. Their simple design translates to a lower initial investment compared to specialized conveying systems. Additionally, their robust construction ensures minimal maintenance requirements, further reducing operational costs. They offer a reliable and efficient way to elevate bulk materials vertically. The continuous loop with buckets ensures a steady flow of material (Skocir, 2018).
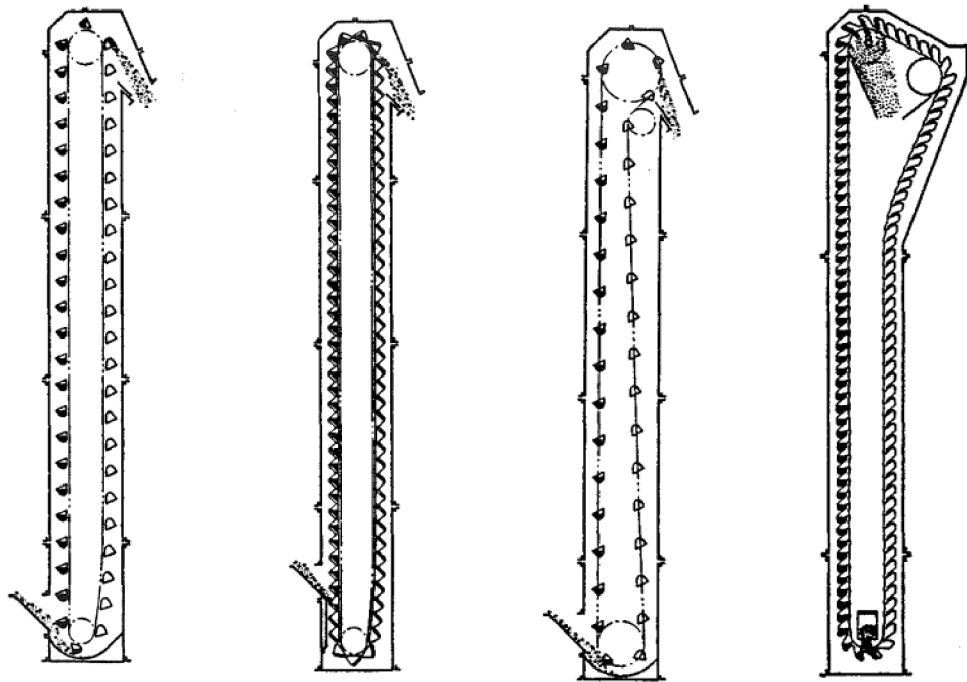
Fig. 3.10: Different types of bucket elevator 1- Centrifugal Bucket elevator 2 – Continues bucket elevator 3 – Positive discharge bucket elevator 4 – Internal discharge bucket elevator (Skocir, 2018)

Bucket elevator vertical design (Fig. 3.10) restricts them to situations where only elevation is required. For horizontal or angled material movement, they are not ideal. The scooping action can degrade delicate materials, making them unsuitable for fragile products. Especially when handling fine powders, bucket elevators can generate significant dust. This necessitates additional dust control measures for a safe working environment. While generally low-maintenance, bucket elevators do require regular inspection, cleaning, and occasional part replacements to ensure smooth operation. Bucket elevators offer a versatile and cost-effective solution for vertically elevating bulk materials. However, their limitations in terms of movement and handling delicate materials should be considered when choosing the right equipment for your specific application (Skocir, 2018).

To select a bucket elevator, multiple key factors should be considered like material characteristics, operational needs, and other factors like maintenance, etc. Understanding the type of material.

Bucket elevators can handle a wide range of materials, but their design needs to be compatible. For instance, abrasive materials require stronger buckets and casings to

withstand wear and tear. The size and shape of the material particles will influence the bucket design and spacing. Large or irregularly shaped materials may require specific bucket configurations to ensure smooth operation and prevent jamming. The weight per unit volume of the material will determine the capacity requirements for the elevator. A heavier material will necessitate a more robust elevator with a stronger belt or chain and larger buckets. Material with high moisture content may require special considerations, such as using waterproof materials for buckets or installing cleaning systems to prevent buildup (Woodcock et al. 1987).

Bucket elevators can utilize either belts or chains. Chains are generally more robust for heavy-duty applications, while belts may be suitable for lighter materials. The ability to control the speed of the elevator can be beneficial for applications requiring precise material flow. Accessibility for inspection, cleaning, and replacement of parts is important for long-term operation and minimal downtime. Safety features like dust control systems, overload protection, and emergency shutoff switches are crucial for operator safety and preventing accidents. Bucket elevator prices vary depending on the factors mentioned above. It's important to find a balance between cost and functionality to meet your specific needs (Fruchtbaum, 1988).

3.4 Storage Time and Temperature Effects

Over a third of the world relies on wheat as their main source of food. It provides more calories and protein than any other grain crop (Yucel et al. 2009). Wheat kernels come in a variety of compositions, with moisture content ranging from 9% to 5%, dry matter between 80% and 90%, and crude protein content varying from 7% to 17%. The price paid for wheat is heavily influenced by its protein content, as this reflects how well it can be used in different products and how desirable it is to consumers (Yucel et al. 2009). Additionally, the amount of moisture in the grain determines how long it can be stored without spoiling (Kibar, 2015).

Heavier grains, all else being equal, tend to yield more flour during milling. In contrast, wheat that's lighter than expected for its variety could be due to several factors: shriveled kernels, abnormal moisture content (too high or too low), or the presence of foreign materials. All these factors can lower the amount of flour ultimately extracted (NZFMA, 2014).

Corn like wheat and other grains as a vital source of food for millions around the globe. It's incredibly versatile, appearing in countless food products for people, being used in various industrial processes, and even serving as animal feed (Gadag et al. 2006; Comertpay et al. 2012). In Turkey, corn is primarily used for animal feed (64%), with the remaining 36% going towards food and industrial applications. For both wheat and corn, proper storage temperature and duration are crucial for maintaining quality. Many studies have examined how storage conditions like grain moisture, weight per thousand kernels, density, and flowability (angle of repose) are affected. Karaoglu et al. (2010) investigated wheat stored at various temperatures (10, 20, and 30°C) for 270 days, finding that higher temperatures seemed to preserve some nutritional qualities. In contrast, our research focuses on the impact of lower storage temperatures on nutritional value, physical characteristics, and handling properties (like flowability) over time. This focus on cooler temperatures aligns with the ideal conditions needed for silo storage.

Researchers have investigated how storage conditions affect wheat and corn. Studies examined factors like dry matter content (Al-Yahya, 2001) and moisture content (Sawant et al. 2012; González-Torralba et al. 2013). Polat (2013) specifically looked at how storage type (concrete, steel silos, etc.) impacts wheat and corn nutritional value over a year. They found significant nutrient loss occurred in soil storage (16.47% for wheat, 21.19% for corn) compared to other methods (less than 4% loss for both). This highlights the importance of proper storage for preserving grain quality.

While existing research explores how moisture content affects properties like bulk density and grain weight, there seems to be a gap in knowledge regarding the impact of storage time and temperature on these aspects for wheat. This includes geometric properties, thousand grain weight, angle of internal friction, and angle of repose. (Molenda et al. 1998; Zaalouk et al. 2009; Markowski et al. 2013).

Previous studies have investigated how moisture content impacts corn during storage. Santos et al. (2012) found that dry matter loss was significantly lower in corn with 14.8% moisture compared to 17.9% moisture after 150 days at various temperatures (15, 25, and 35°C). Additionally, Taffarel et al. (2013) examined bulk density and thousand grain weight after 4 months of storage. However, there's a lack of research on how storage time and temperature affect other properties like geometric shape,

internal friction angles, flowability (angle of repose), and surface friction (static coefficient of friction) for corn. While Gadag et al. (2006) and Seifi and Alimardani (2010) explored the influence of moisture content on these properties, the impact of storage conditions remains unexamined.

Designing proper storage facilities for grains relies on understanding their individual and collective behavior under different conditions. This includes properties like bulk density, flowability (angle of repose), resistance to internal friction (angle of internal friction), and surface friction (static coefficient of friction). Researchers like (Jenike, 1964; Reimbert et al. 1987; Gokalp et al. 2010) have explored these bulk properties for various grains.

Kibar (2015) examined how storing wheat and corn grains for 90 days under three different temperatures affects various functional properties. These properties include moisture content, grain shape, dry matter content, protein and fiber content, weight per thousand kernels, bulk density, resistance to internal and sliding friction, and how easily the grains flow.

Kibar's (2015) study showed that storing wheat and corn for 90 days at various temperatures (10, 12, and 14°C) led to a decline in their functional properties. This decrease was mainly attributed to a drop in grain moisture content. This highlights the importance of maintaining consistent storage conditions to meet the specific needs of the grains. Fluctuations in temperature and moisture levels can accelerate physical and chemical deterioration, resulting in nutritional value loss. To gain a deeper understanding of wheat and corn behavior in storage, further research is needed. These studies should explore the impact of various postharvest treatments, storage durations, and a wider range of moisture content levels on the chemical properties and overall quality of the stored grains.

3.5 Storage Systems Overview

Effective grain storage goes beyond just putting it away. It's a process that demands care, knowledge, and dedication from those involved. Preserving the quality, health benefits, and nutritional value of grains throughout storage hinges not just on how they're grown and harvested, but also on proper storage conditions and consistent maintenance (Mobolade et al. 2019).

Even though grains seem tough due to their unique design, they're vulnerable to various threats during storage. These include insects, mites, microorganisms, rodents, birds, and even damage that happens before they're stored. This can lead to physical damage, changes in their chemical makeup, and the development of toxins. As a result, the grains lose quality and nutritional value, and their commercial worth plummets. They may even become unfit for human consumption or industrial use (Mohapatra et al. 2017; Neme et al. 2017).

To ensure safe storage, factors like the grain's initial condition, biological and physical integrity, health, cleanliness, and moisture content are crucial. Storage losses can be either quantitative due to reduction in weight due to grain metabolism or pests, or qualitative because of loss of nutrients, ability to germinate, and commercial value due to contamination or improper storage (Paraginski et al. 2014; Fleurat-Lessard, 2017). There are different storage systems available, conventional (non-hermetic) methods, semi-hermetic or bulk like horizontal or vertical silos, and warehouses, hermetic, refrigerated, and modified atmosphere storage.

3.5.1 Conventional System

The most common type of grain storage, called non-hermetic or conventional storage, comes in various forms. It can be as simple as a room or barn for smaller quantities, or it can involve larger, more technical warehouses for bigger operations. Traditionally, these systems rely on storing grains in sacks made from different materials and sizes. In areas with high production, larger bags holding up to 1 ton (1000 kg) of grain are becoming more popular. These bigger bags are easier to transport thanks to machinery designed for agricultural use (Mobolade et al. 2019).

A benefit of conventional storage is the ability to store different grains in the same warehouse. You can also separate high-quality grains from lower-quality ones during storage, which isn't possible with bulk storage systems. However, this system requires the grains to be drier than what's traditionally recommended for storage. This is because conventional storage allows for more air and temperature exchange with the environment, raising the risk of moisture-related spoilage (Demito et al. 2019).

While conventional storage offers some advantages, it does have drawbacks. First, it requires packaging like bags, which may or may not be reusable. Additionally, the

grains need to be kept off the floor using pallets to prevent moisture build-up and spoilage. These pallets take up space and limit how high you can stack the grains. There are also restrictions on pile size and spacing between piles to ensure proper air circulation. All these requirements can reduce storage capacity by about 20% compared to bulk storage systems. However, conventional warehouses are still the preferred option for storing larger quantities of grains compared to smaller storage units like rooms or barns (Befikadu, 2014).

This type of storage is popular with grain farmers and cooperatives who store various grains together. After cleaning and drying, the grains are placed in bags and stay there until they're sold or used. However, pests like insects can sometimes get inside the bags during sampling. If this happens, the grains need to be fumigated with phosphine gas (PH_3) using metal nozzles inserted into the bags. To ensure the fumigation's effectiveness, all the bags are covered with high-density plastic sheeting. Additionally, special seals called "sand snakes" are used around the fumigation area to prevent the phosphine gas from escaping into the environment (Demito et al. 2019).

3.5.2 Semi-Hermetic or Bulk System

The semi-hermetic storage system, also known as bulk storage, is a popular option. Unlike conventional storage, it allows some gas exchange between the grain and the surrounding environment. This exchange is less than non-hermetic systems but more than hermetic systems (Coradi et al. 2020). Bulk storage has some limitations. Because the grains are stored in large quantities, it's difficult to separate them by type or inspect them directly. Taking samples can also be challenging. Maintaining grain quality or controlling temperature relies on indirect methods like using thermometers. Cable systems with thermocouples, made from specific metal alloys, are commonly used for temperature monitoring (Tefera et al. 2011).

Bulk storage excels at storing large amounts of grain while offering precise control over the internal environment. This translates to better grain quality preservation compared to conventional methods. As a high-tech system, it boasts low maintenance costs by eliminating the need for bags and pallets. However, there's a limitation: typically, only one type of grain can be stored at a time. Unlike conventional warehouses, bulk storage systems don't require dedicated space for people or equipment to move around. They do need an empty space of about 1.5 meters near the

ceiling. This space serves multiple purposes: allowing for inspections, accommodating the natural expansion of grain volume as it settles over time, and helping regulate temperature within the silo (Demito et al. 2019).

Silos need a space of at least 1.5 meters between the grain and the ceiling. This is especially important on hot days to prevent condensation from forming on the ceiling. Condensation can happen because the silo walls and roof absorb heat, causing the temperature inside to rise. If the grain is too close to the ceiling, there's not enough space for the hot air to circulate. This hot air traps moisture, which then condenses on the cooler ceiling, dripping back down onto the grain and potentially spoiling it. To avoid this issue, exhaust fans can be installed in silos and warehouses to help remove hot air and maintain a more consistent temperature. Bulk storage systems, like vertical silos and large warehouses, rely on ventilation to preserve the quality of pre-dried grains. This ventilation process, called aeration, uses fans to circulate unheated air from outside the silo. In some cases, other methods like Transillation and Intrasilage are used for grain preservation within the same system. Transillation involves completely moving the grain from one storage unit to another. Intrasilage involves partially moving the grain within the same storage unit (Demito et al. 2019).

Aeration is like controlled ventilation for grain. By drawing in outside air with fans, aeration helps cool down the grain mass and keep the temperature consistent throughout. This helps preserve the grain by slowing down the natural respiration of the grains and any insects or mites present. Aeration is especially important to prevent two things. On hot days, the grain near the silo walls heats up faster than the grain in the center. This creates warm air currents that rise along the walls. If air circulation is poor, the center of the grain mass can become oxygen depleted. This can create an environment for spoilage (Lopes et al. 2006).

Air circulation within a silo can create condensation problems. As warm air moves through the grain mass, it picks up heat and moisture. This warm, moist air can condense into water droplets when it reaches cooler areas. This can happen in two main ways. Warm air near the silo walls heats the surrounding grain. This warm air rises, carrying moisture with it. If the center of the grain mass is cooler (especially in the lower third of the silo), the warm, moist air can condense on the cooler grains, leading to spoilage. When the outside air is cold, the walls of the silo cool down. The

cool air near the walls sinks, pushing warm, moist air from the center upwards. This warm air can condense on the cold silo roof, forming droplets that drip back down onto the grain. These condensation problems are more common in areas with frequent temperature fluctuations (Lopes et al. 2019).

Regular air circulation (aeration) is crucial to stop temperature swings inside the silo from affecting the grain's properties and quality. Specially designed fans for each silo size ensure proper airflow and pressure throughout the stored grain. This process takes time and relies on suitable weather conditions, specifically cool and dry air. (Demito et al. 2019).

The introduction of hot and humid air into the stored grain mass can induce a cascade of detrimental effects. Over time, this exposure elevates internal temperature and humidity, leading to an acceleration of the grain's respiratory processes. This heightened metabolic activity creates a favorable environment for the proliferation of insects and fungal growth within the grain bulk, ultimately compromising the stored grain's quality. (Lopes et al. 2019; Lopes et al. 2006).

The implementation of air-cooling systems facilitates the safe modification of the grain mass's aeration state. To complement forced aeration techniques, eolic exhausters can be employed. Strategically positioned at the silo's apex, these devices leverage wind energy and silo pressure differentials to rotate their fins, thereby inducing air extraction from the grain bulk (Da Silva et al. 2014). Beyond aeration, two additional strategies can be employed to promote grain ventilation: Transillation and intra-silo movement. Transillation involves the complete transfer of grain from one silo to another or, in multi-cell warehouses, from one cell to another. Conversely, intra-silo movement entails the partial transfer of grain through an elevator system, followed by its return to the original cell or silo. While aeration utilizes fans to force air through the static grain mass, both Transillation and intra-silo movement involve the physical movement of grain through ambient air facilitated by an elevator (Demito et al. 2019).

For vertical silos, particularly those of significant height, the practice of Transillation during loading becomes crucial to minimize grain damage from excessive pressure. As the grain mass reaches approximately one-third of the silo's maximum capacity, selective extraction is necessary. This process targets the central portion of the grain

mass, which often concentrates broken kernels and impurities. The extracted grain undergoes a thorough cleaning process before being reintroduced into the top of the remaining grain bulk. This cycle of partial unloading, cleaning, and reloading is repeated at two-thirds and again upon reaching full capacity. Notably, Transillation is not limited to vertical silos and can be effectively implemented in bulk warehouses as well (Ziegler et al. 2021).

The selective removal of broken grains, foreign matter, and impurities concentrated in the center of silos and warehouses enhances both the grain aeration process and overall grain preservation. During aeration, the presence of broken grains can impede airflow reaching the grain surface due to increased static pressure. Air preferentially travels through areas with less resistance, thereby bypassing regions with high concentrations of broken grains. Furthermore, compromised physical integrity makes broken grains more susceptible to fungal growth and insect infestation. Additionally, the increased respiration rate in broken grains accelerates the breakdown of dry matter through lipid, protein, and carbohydrate degradation. This degradation results in reduced grain weight often misidentified as "technical breakdown." However, by implementing proper storage processes and techniques, these detrimental effects and associated grain losses can be effectively mitigated (Jian et al. 2019).

3.5.3 Hermetic System

Hermetic The hermetic storage system exhibits limitations when dealing with large grain volumes. Consequently, smaller containers like casks, drums, and 'plastic silos' are more commonly employed for hermetic storage. In emergency situations, 'sack pools' represent the most frequently utilized option. However, recent advancements have introduced emergency warehouses as a viable storage alternative for producers seeking to leverage hermetic technology for larger-scale grain preservation. (Demito et al. 2019).

Hermetic storage for dry or wet grains leverages a modified atmosphere to control biological activity. It achieves this by depleting oxygen to levels detrimental or inhibitory for associated organisms. This depletion occurs via natural grain respiration, initial air removal upon sealing, or, in specific cases, burning organic materials within the container. The resulting CO_2 enrichment, a byproduct of respiration, acts as a preservative within the hermetic environment, inhibiting enzymatic activity in the

grains and organisms, ultimately leading to microbial mortality. (Govereh et al. 2019; Odjo et al. 2020).

Hermetic storage environments specifically target insect populations by suppressing their activity, and development, and potentially inducing paralysis. (Odjo et al. 2020). Hermetic grain storage effectiveness relies on several factors: grain moisture content, storage duration, inter-granular temperature, inherent resistance of the grain species, and its developmental stage. While oxygen depletion is the primary mechanism, the limited aerobic/anaerobic environment fosters incomplete carbohydrate metabolism in the grain and by residual organisms. This, along with the presence of bacteria and yeasts, leads to the formation of ethyl alcohol and short-chain organic acids (acetic, lactic, and butyric). These secondary metabolites, though offering a preservative effect, can alter the stored grain's sensory characteristics (odor and flavor) and may persist even after storage. (Baributsa et al. 2020).

Hermetic storage of grains for animal feed can offer a potential nutritional benefit. The partial breakdown of carbohydrates and proteins into readily absorbable simple sugars and amino acids, respectively, can enhance their digestibility by animals. However, hermetic conditions present a crucial technical consideration: CO_2 production during storage leads to a significant internal pressure buildup within the structures. This pressure is directly proportional to the grain moisture content. Therefore, careful planning of hermetic storage structures for grains necessitates accounting for this pressure factor. Maintaining airtightness is paramount for the system's effectiveness. Any breach that allows gas exchange compromises the efficiency and can lead to a decline in grain quality, particularly over extended storage periods (Demito et al. 2019).

This hermetic storage system presents a viable alternative for small-scale producers, particularly family farms. It utilizes repurposed plastic packaging typically discarded after consuming soft drinks. These containers, once thoroughly washed and dried, can be filled with grain to minimize air pockets within. The inherent respiratory process of the grains then depletes the remaining oxygen, creating an airtight environment. This approach offers several advantages compared to traditional sack storage: improved grain color preservation and overall quality characteristics throughout the storage period. (Scariot et al. 2018; Odjo et al. 2020; Mlambo et al. 2017).

3.5.4 Refrigeration System

Artificial cooling is becoming increasingly popular, and for good reasons. This technology lowers the temperature of the grain mass from around 25°C to a cooler 15°C. This cooler environment has two major benefits. By slowing down the grain's natural respiration process, artificial cooling minimizes quality loss. Insects thrive in warm environments. By keeping the temperature below 17°C, insect development slows down dramatically, protecting the grains from infestation (Ziegler et al. 2016; Paraginski et al. 2014; Demito et al. 2019; Ferreira et al. 2018).

Special equipment cools down the air before it reaches the grain. This equipment lowers both the air's temperature and moisture content. This cold, dry air is then blown into silos and tall warehouses to cool the grain mass. It's a slow process, similar to aeration, because a cooling zone needs to move through all the grain. The cooling time depends on the amount of grain stored and especially the height of the silos. Producers interested in artificial cooling don't have to invest in expensive equipment themselves. Companies now offer refrigeration services, making this technology more accessible. Grains act like natural insulators, so once cooled, they stay cool for a long time. How long depends on the moisture levels in the storage unit's air. The good news is that constant cooling isn't necessary. A silo can be cooled once, and the equipment moved to another. Then, it can return later for another round of cooling. Temperature sensors (thermometry systems) help producers monitor grain temperature and determine when re-cooling is needed (Dincer, 2017).

3.5.5 Modified Atmosphere System

For producers looking to extend shelf life and potentially earn more during off-season sales, modified atmosphere storage offers a promising alternative. This technology, already adopted by many, involves storing grains in a controlled environment with an adjusted gas mixture (Rupollo et al. 2011). Compared to conventional storage, modified atmosphere helps maintain grain quality, potentially leading to higher profits when prices rise. Additionally, some companies now specialize in building smaller metal silos (around 300,000 kg capacity) specifically for this type of storage. These smaller silos allow for better monitoring and control of the stored grain, particularly for legumes like beans (Lindemann et al. 2019).

Storing grains in a controlled atmosphere keeps them fresher for longer, fetching a higher price at market. This method not only prevents darkening, hardening, and insect infestations, but also improves how the grains cook. Compared to conventionally stored grains, they have a richer broth (higher solid content), more soluble protein, and a softer texture – all qualities that boost their commercial value and put more money in the producer's pocket (Rupollo et al. 2011; Lindemann et al. 2019).

Modified atmosphere storage takes a different approach than traditional methods. Instead of relying on dry or wet storage, it controls the gases surrounding the grains. This technique specifically reduces the oxygen (O_2) levels to a point that suffocates or limits the growth of insects and other living organisms that might harm the grains. It also slows down the grain's natural respiration process. To achieve this controlled environment, nitrogen (N_2) or carbon dioxide (CO_2) is pumped into the storage unit, further reducing the available oxygen (Jayas et al. 2002; Moncini et al. 2020).

For modified atmosphere storage, nitrogen (N_2) is the preferred gas because high levels of carbon dioxide (CO_2) can be dangerous for workers due to its toxicity. Nitrogen is readily available, and companies specialize in supplying it to producers. Another option is using special polyethylene bags. These extra-thick, gas-impermeable bags are machine-packaged with oxygen removed and nitrogen added. This creates a controlled atmosphere within the bag that persists throughout storage (Ziegler et al. 2019).

3.6 Storage Methods and Changes During Storage

3.6.1 Grain Preservation Challenges

The process of storing grains demands meticulous care, knowledge, dedication, and professionalism to ensure the preservation of their quality, health, and nutritional value throughout the storage period. Preserving grain quality depends not only on production and harvest conditions but also on maintaining appropriate storage conditions to mitigate losses caused by various factors (Mobolade et al. 2019).

3.6.2 Factors Affecting Grain Quality

Grains, despite their inherent resistance, are susceptible to attacks by insects, mites, microorganisms, rodents, birds, and other animals. They may also undergo mechanical

damage, biochemical changes, and non-enzymatic chemical effects even before storage, leading to quantitative and qualitative losses. These losses include changes in chemical composition, reduction in nutritional value, and the development of toxic substances, ultimately compromising their suitability for consumption or industrialization (Mohapatra et al. 2017; Nemeet al. 2017).

3.6.3 Quantitative and Qualitative Changes During Storage

During storage, grains experience both quantitative and qualitative changes. Quantitative losses, primarily observed as reductions in dry matter content, reflect the metabolic activities of grains and associated organisms. Qualitative losses, however, stem from chemical and enzymatic reactions, the presence of foreign matter, impurities, and microbial attacks, resulting in diminished nutritional, germinative, and commercial value. Improper storage practices can even lead to the formation of toxic substances within stored grains (Paraginski et al. 2014; Fleurat-Lessard, 2017; Demito et al. 2019).

3.7 Types of Warehouses and Storage Factors in Grain Management

Safe storage of grain is paramount to maintain both its quality and quantity. Several factors need to be monitored to ensure that grains are stored appropriately, safeguarding them from various risks. These risks include exposure to weather elements, mold, microorganisms, moisture, high temperatures, insects, rodents, birds, objectionable odors, contamination, unauthorized distribution, and potential theft (Sadaka & Rosentrater, 2019).

3.7.1 Underground Storage

Historically, underground storage has been a principal method for accumulating grain surpluses. It offers protection against temperature fluctuations, insects, and mold due to low oxygen and high carbon dioxide levels once sealed. However, drawbacks include high handling costs and flooding risks (Rosentrater, 2022).

3.7.2 Bagged Storage

Bags provide convenient storage options for grains, with various materials used worldwide. Bagged storage is common for small-scale food and beverage manufacturers, feed stores, and small farms. For larger facilities, flexible intermediate bulk containers or super sack bags are preferred, although they require forklifts for handling (Christensen et al. 1969).

3.7.3 Farm Bins

Farm storage bins are essential for holding crops after harvest, delaying marketing decisions, and enabling on-farm consumption. Steel grain bins are predominant, offering customizable sizes and capacities. Flat storage structures have also become popular, especially for corn storage, accommodating increasing yields and production uncertainties (Channaiah & Maier, 2014)

3.7.4 Bin Sites

Bin sites, once used for US government grain surplus, feature steel or wooden bins for temporary storage. These sites, established during the 1950s and 1960s, have evolved but are no longer maintained due to policy changes, leading to the cessation of emergency grain supplies (NAVARRO et al. 2005).

3.7.5 Country Elevators

Country elevators receive grain from producers, providing drying, storage, and loading services. Historically made of wood, modern elevators feature concrete silos or steel bins, with some utilizing ground piles for cost-effectiveness (Rosentrater, 2022).

3.7.6 Terminal/Export Elevators

Terminal elevators serve as transportation hubs for grain, offering storage and loading services for domestic and international markets. These facilities, located in key coastal and inland areas, handle large volumes of grain with high throughput equipment (Baributsa & Njoroge, 2020)

3.7.7 Ground Piles

Ground piles, once used for emergency storage, have become common at country elevators and processing plants due to cost considerations. These piles, covered with polyethylene tarps, offer a cost-effective alternative to concrete or steel storage (Christensen et al. 1969).

3.7.8 Storage at Processing Plants

Processing plants require onsite grain storage for manufacturing various products. Facilities vary in storage requirements, ranging from small bags to large silos, depending on daily throughput and processing needs (Rosentrater, 2022).

In conclusion, monitoring and managing various types of warehouses and storage options are critical for ensuring the safe storage of grains, maintaining their quality, and mitigating risks associated with storage and handling. Each storage method offers unique advantages and considerations, necessitating careful evaluation based on specific needs and operational requirements (Caughey et al. 1951).

3.8 Silo vs. Floored Warehouse: A Comparison

3.8.1 Structural Design and Purpose

3.8.1.1 Silo: Silos are tall structures with shaft chambers designed for storing dry grain with moisture content up to 14%. Silo cells are typically circular or hexagonal in shape and made of ferroconcrete or metal. Designed for long-term storage of grains with minimal exposure to external conditions (Angelovič et al. 2018).

3.8.1.2 Floored Warehouse: Hangar-type warehouses are used for grain storage, seed storage, and temporary storage of damaged stock. These warehouses have a more complex built-in ventilation system compared to silos. Intended for various storage needs and may handle grains with slightly higher moisture content (Williams, 2017)

3.8.2 Temperature and Moisture Regulation

3.8.2.1 Silo: Average temperature inside the silo during the study was 12.3°C, with fluctuations between 7.8°C and 21.4°C. The average moisture content of maize grain stored in the silo was 13.6%. Silos provide a controlled environment with lower

average temperatures, contributing to better moisture retention (Afzal, 2017).

3.8.2.2 Floored Warehouse: The average temperature inside the warehouse was higher at 21.9°C, ranging from 12.6°C to 32.6°C. Maize grain stored in the warehouse had an average moisture content of 13.7%. Warehouses experience greater temperature fluctuations, potentially impacting moisture levels and grain quality (Williams st al. 2017).

3.8.3 External Storage Conditions

3.8.3.1 Silo: External conditions during silo storage were monitored, with an average atmospheric temperature of 9.17°C and an average moisture content of 86.5%. Silos are less susceptible to external influences due to their enclosed structure (Marks et al. 1995).

3.8.3.2 Floored Warehouse: The warehouse also experienced external conditions, with an average atmospheric temperature of 14.8°C and an average moisture content of 86.8%. Warehouses are more affected by external factors, which can influence internal temperature and moisture levels (Angelovič et al. 2018).

3.8.4 Pest Control and Grain Stability: For both, no occurrences of animal pests were recorded during the storage period in either the silo or the floored warehouse. Grain stability depends on maintaining optimal moisture levels, typically around 12%, to prevent deterioration and pest infestation (Lopez et al. 2008).

In conclusion, silos offer better temperature regulation and moisture retention compared to floored warehouses. Floored warehouses experience greater temperature fluctuations, potentially impacting grain quality. Both storage facilities emphasize the importance of controlling external storage conditions for maintaining grain quality and stability. While both silos and floored warehouses serve as storage facilities for maize grain, they differ in structural design, temperature and moisture regulation, susceptibility to external conditions, and pest control measures. Silos provides a more controlled environment conducive to preserving grain quality, whereas floored warehouses may experience greater fluctuations in temperature and moisture levels, posing challenges to maintaining grain stability over time (Williams et al. 2017).

4. Methodology

This diploma aims to assess grain mechanical damage during transportation via belt conveyors and chain conveyors which are widely used in the postharvest systems of Czech agriculture. Based on our measurements and literature reviews, belt and chain conveyors are more favorable to transported grain and are therefore preferable for horizontal grain transport in facilities for receiving, processing, and storing food grain crops.

After the sampling of the chosen type of grainy material, all the cereal quality assessment was done by testing in the laboratory. Lab boasts a comprehensive suite of equipment designed to process and analyze cereal samples throughout the entire evaluation process, from initial product purchase to final use. This advanced technology allows for the evaluation of grain in various forms, including whole grains, broken kernels (scrap), flour, and even dough, considering both milling and baking perspectives. Additionally, a dedicated laboratory grinder enables the preparation of flour for analysis or the creation of pastry samples for bakery experiments.

4.1 Compliance with Standards or new ČSN relating to cereals

Harmonized or new technical standards for cereals are issued by the Czech Standardization Office Institute in Prague. The sampling procedure adheres to the Standards ČSN ISO 950, and qualitative requirements for food grain, including wheat and malt barley, are referenced from the following Standards: ČSN 46 1100–2 (Wheat) and ČSN 46 1100–5 (Malt barley). Requirements for the quality, control, and delivery of cereals intended as raw material for human consumption nutrition are determined by the standards ČSN 46 1100 - Food grains are listed below:

- ČSN 46 1100-2 Food grains – Part 2: Food wheat. Effective from 1/7/2001.
- ČSN 46 1100-3 Food grains – Part 3: Durum wheat. Validity from 1/7/2001.
- ČSN 46 1100-4 Food grains – Part 4: Rye. Effective from 1/7/2001.
- ČSN 46 1100-5 Food grains – Part 5: Malting barley. Effective from 1/1/2006.
- ČSN 46 1100-7 Food grains – Part 7: Food oats. Effective from 1/7/2001.
- ČSN 46 1100-8 Food grains – Part 8: Food maize for mills processing. Valid from 1/7/2020.

4.2 Method

According to the reviews, the screw conveyors of a one horizontal meaning of the transporting route are mainly used for transporting impurities, small or crushed grain after cleaning and sorting section of the postharvest line. Due to the huge amount of damage to the grains during the transportation cycle, screw conveyors were excluded from investigation in this diploma thesis.

The methodology employed in this diploma involves the following steps and considerations:

1. Objective Definition: The primary objective is to determine the extent of grain damage during transport using different types of conveyors commonly used in the postharvest period in the Czech Republic.

2. Transport Systems Under Investigation: While several conveyor types exist, two commonly used options in the Czech Republic are belt conveyors and chain conveyors. Belt conveyors are evaluated in terms of performance, transport distance, belt width, and transport belt velocity. Chain conveyors examined concerning performance, transport distance, and technical specifications. Due to the huge amount of damage to the grains during the transportation cycle, screw conveyors were excluded from investigation in this diploma thesis.

3. Sampling Methodology: The experiment involved collecting grain samples at two stages: before and after they passed through a conveyor belt or chain conveyor. Three separate samples, each weighing approximately 2-3 kg, were collected over a 2 to 3-minute period at each stage. To ensure representative samples, small portions were collected continuously during this timeframe. There was a waiting period of roughly 15 minutes between collecting samples within a single test. All tests were conducted using the same type of wheat which in this diploma thesis is Julie.

The grain samples were collected from the receiving basket / income bin, the conveyor itself (belt), and after a brief holding period in the handling bin (just after discharge to the chain conveyor). Details regarding the laboratory analysis procedures can be found in the diploma thesis appendix. Grain sampling began when the receiving basket beneath the belt conveyor was filled. Next, the handling bin is filled before reaching the drying section. Upon filling, this bin was gradually emptied onto the chain

conveyor, where three samples were collected using the same method. After a time determined by the stable conveyor's speed, samples were again taken as the grain exited the belt or chain conveyor. The moisture content of each sample was analyzed before entering the conveyor. Finally, after thorough mixing, two separate 100g reference portions were taken from each sample for further individual processing.

The grain samples were divided into distinct categories based on weight: fractions (broken pieces smaller than half a grain), other mechanically damaged grain (whole grains larger than half with cracks or abrasions from handling), undamaged grain (whole grains with no visible damage), and impurities. Impurities include any foreign material like weed seeds, straw or weed plant parts, mineral admixtures like dirt or rocks, and seeds from other cereal types.

After weighing the grain, it was separated into undamaged kernels, fragments in which the pieces are smaller than half a grain, and other mechanically damaged grains which the whole grains with cracks or abrasions larger than half the size. The total weight of these three categories was then used as the baseline to express the % portion of fragments and other mechanically damaged grain as a percentage.

4. Evaluation Parameters: Grain damage was assessed in terms of fractions created, total mechanical damage, and the impact on grain quality indicators such as moisture content, volume weight, and performance class. The experimental part of the diploma thesis was focused on marked section A, in Fig. 4.1. It was the part of the chosen postharvest line in the farm in the middle part of the Czech Republic. This part is used for gathering of the grainy material in, then there is pre-cleaning and cleaning/sorting section with all necessary transporting routes in horizontal and vertical way. There is connected also drying section with handling bins. All the steps of the sampling are marked in Fig. 4.1.

Fig 4.1: Postharvest diagram

1- Income Bin

2, 14, 19, 29, 33 - Belt Conveyors

3, 11, 15, 31 - Bucket Elevators

4 - Aspiration Chamber

11, 22, 25 - Manipulative Tower Trays

17 - Tower Trays Capacity 1000 t per one unit

7, 13 - Elements for regulation / splitting of grain flow

8 - Sieving Machine

9 - Asspiration Pre-Cleaning

10 - Screw Conveyor

5, 18 - Ventilation

6 - Dust Chamber

21 - Expedition Bins

27 - Drying Section
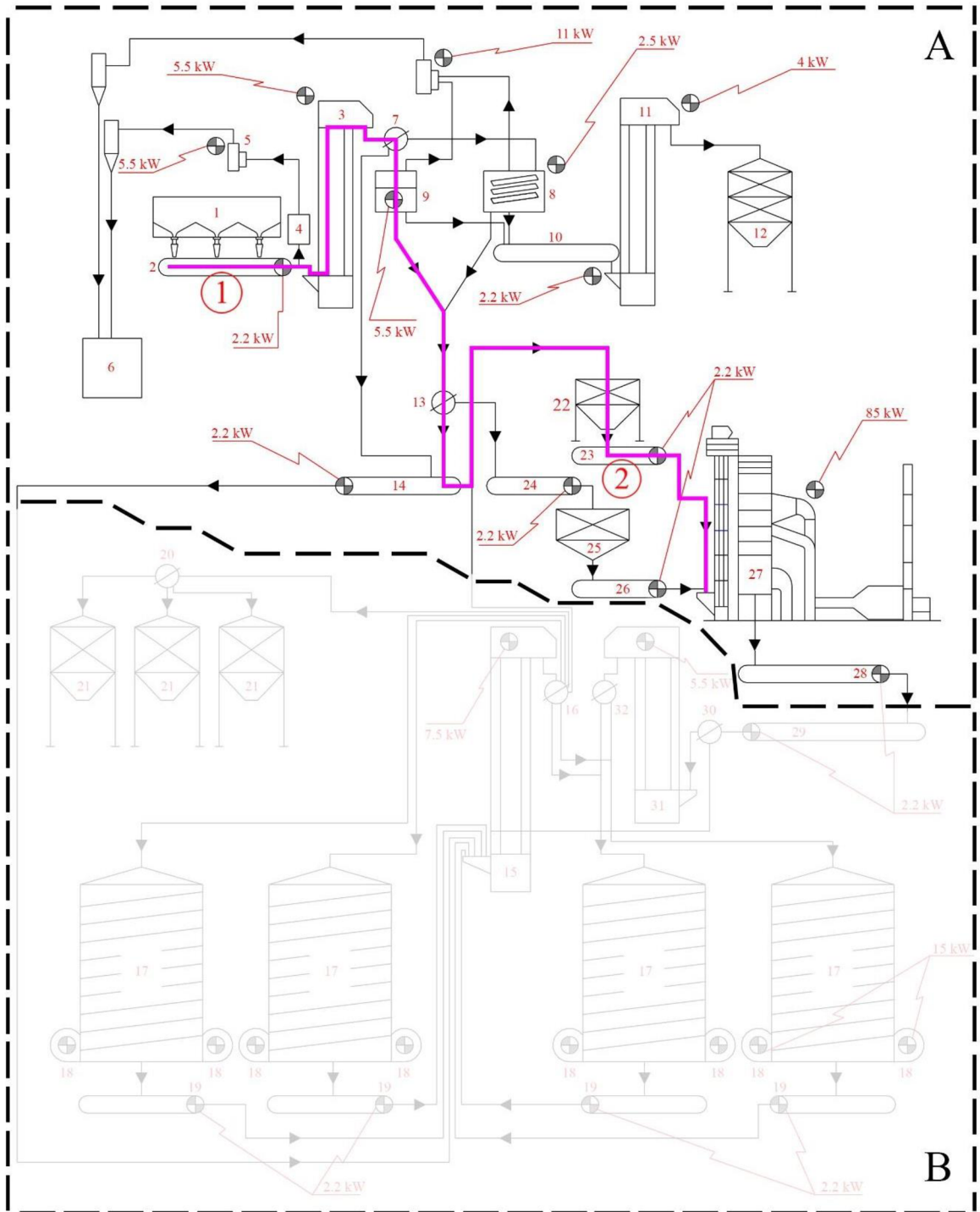
23, 24, 26, 28 - Chain Conveyor

①② - Sampling Point

— Transport Route

Section A in Fig. 4.1, of the postharvest treatment line, where grain material is received in the income bin (1) and subsequently conveyed to the cleaning/sorting section (8). Here, the material is evaluated based on its properties, particularly moisture content. If the moisture content exceeds the threshold of 15-17%, the grain can either bypass this section (12) or proceed to the drying section (27) for moisture reduction. The primary area of investigation concerns the impact of damage during transport within section A on the chosen type of grain. The hypothesis is that conveying grain using two types of conveyors: a chain conveyor as opposed to a belt conveyor increases its overall mechanical damage. It was the standard moisture content to 14%, because of the dry weather during the harvest time in the chosen farm.

To facilitate analysis for Fig 4.1, a breakdown of the route's technical and technological data is presented here:

- Income performance 48 t.h^{-1} (1)
- Grain pre-cleaning (aspiration pre-cleaning) 64 t.h^{-1} (9)
- (Storage capacity 4 x 1,000 t (17)
- Grain cleaning/sorting performance 38 t.h^{-1} (8)
- Maximum moisture content of stored grain: 14%
- Drying efficiency (maize) 7 t.h^{-1} (drying from moisture 30% to 15%) (27)
- Grain expedition bins - storage capacity 4 x 55 t (12; 22)

5. Data Analysis: Measured results from each type of conveyor were analyzed to determine the extent of grain damage and its implications. Results were compared across different conveyors, performance classes, and operating conditions to draw meaningful conclusions.

6. Discussion of Results: Findings were discussed in relation to specific conveyor types, operating conditions, and their impact on grain damage. Factors such as conveyor filling methods, transport distances, and technical conditions were considered in interpreting the results.

7. Conclusion and Implications: Conclusions were drawn regarding the tendencies of each type of conveyor in causing grain damage. Implications for postharvest systems and grain market production were highlighted, emphasizing the importance of minimizing grain damage during handling and transport.

5. Results

The grain quality parameters were assessed in the Faculty of Agrobiology and Natural Resources (FAPPZ), the Cereal Quality Testing Laboratory at the Department of Food Quality and Safety. The cereal quality testing laboratory is comprehensively equipped with equipment for the processing and analysis of cereal samples according to the purchase evaluation of the products.

At the 1st measuring point, a belt conveyor, model ND-085, is located on the postharvest line under a receiving hopper (Fig. 5.1). It carries grain for pre-cleaning by aspiration and then transports it to the cleaning and sorting section on a sieve cleaner manufactured by TOROFA, s.r.o. The conveyor has a maximum capacity of 75 tons per hour (t.h^{-1}), travel distance of 12 meters (m), and has a belt width of 650 millimeters (mm). The belt speed is 1.9 meters per second (m.s^{-1}) and the installed power is 1.8 kilowatts (kW).

Fig. 5.1: Belt Conveyor measuring point under the income bin (Photo by author, 2023)

At the 2nd measuring point, a chain conveyor (type RŽ 280) is beneath a 34-ton handling hopper (Fig. 5.2). This hopper is one of several tower trays within the whole postharvest line that provide short storage of grain, the capacity for long term storage is 4,000 tons. The RŽ 280 conveyor efficiently transfers grain at a maximum rate of 34 tons per hour (t.h^{-1}) over an 18-meter distance. The conveyor features a 250-millimeter (mm) wide inner transport chute with a chain link spacing of 150 mm. The chain travels at a speed of 0.7 meters per second (m.s^{-1}) to steadily feed grain to the drying section following aeration in the handling hopper.

Fig. 5.2: Chain Conveyor measuring points (Photo by author, 2023)

5.1 Chain Conveyor

This diploma thesis investigated grain damage caused by standard chain conveyor with a rated capacity of 12 and 28 tons per hour ($t.h^{-1}$). The conveyor transported grain over distance 18 meters. The basic technical parameters of the chain conveyor are listed in the table 5.1:

Performance ($t.h^{-1}$)	Stable output ($t.h^{-1}$)	Inner width of transport trough (cm)	Chain links pitch (cm)	Transport chain velocity ($m.s^{-1}$)	Output (kW)
34	28	25	15	0.7	7.5

Table 5.1: Basic technical parameters of the chain conveyor

Sample Number	Crops	Volume weight (kg.hl⁻¹)	Grain moisture (%)	Fraction amount			Total mechanical damage		
				before chain conveyor (%)	behind chain conveyor (%)	increased by conveyor (%)	before conveyor (%)	behind conveyor (%)	increased by conveyor (%)
1	Julie	82.3	13.7	0.23	0.31	0.08	0.62	0.93	0.31
				0.27	0.39	0.12	0.70	0.97	0.27
2	Julie	82.3	13.8	0.24	0.37	0.13	0.67	0.92	0.25
				0.32	0.44	0.12	0.72	0.95	0.23
3	Julie	82.1	13.8	0.28	0.40	0.12	0.64	0.88	0.24
				0.22	0.38	0.16	0.76	1.03	0.27
Total average			13.77	0.26	0.38	0.12	0.69	0.95	0.26

Table 5.2: Grain damage by chain conveyor, performance 28 t.h⁻¹
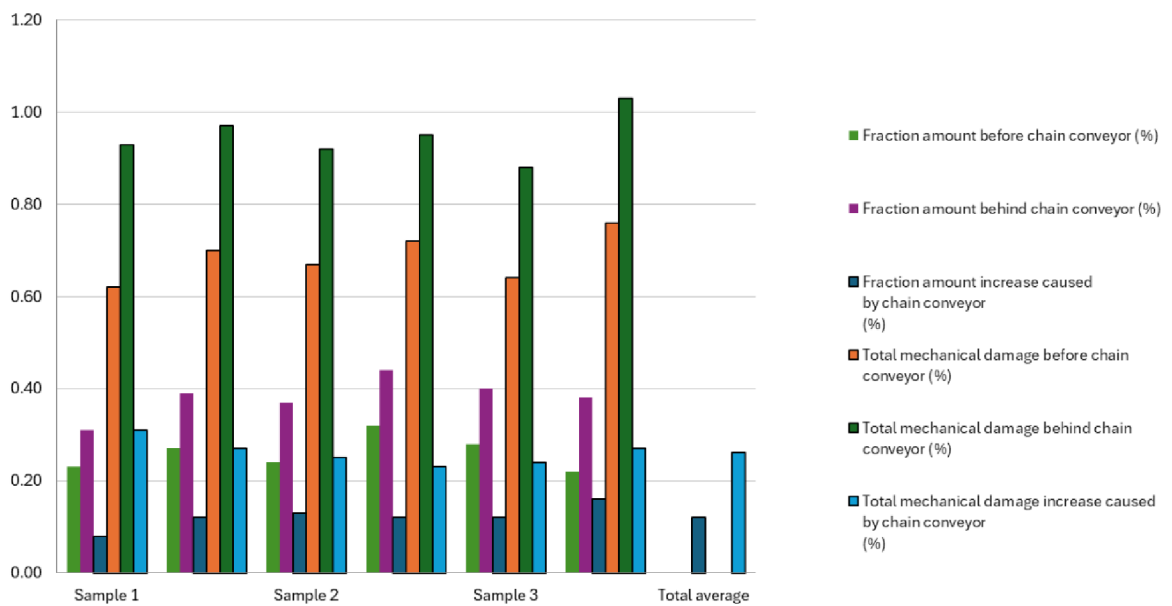
Fig 5.3: Grain damage by chain conveyor, performance 28 t.h⁻¹

Sample Number	Crops	Volume weight (kg.hl^{-1})	Grain moisture (%)	Fraction amount			Total mechanical damage		
				before chain conveyor (%)	behind chain conveyor (%)	increased by conveyor (%)	before conveyor (%)	behind conveyor (%)	increased by conveyor (%)
1	Julie	82.1	13.6	0.25	0.42	0.17	0.54	2.43	1.89
				0.23	0.39	0.16	0.56	2.38	1.82
2	Julie	82.2	13.5	0.22	0.33	0.11	0.62	2.52	1.90
				0.27	0.39	0.12	0.64	2.56	1.92
3	Julie	82.1	13.7	0.25	0.37	0.12	0.77	2.74	1.97
				0.24	0.40	0.16	0.72	2.66	1.94
Total average			13.60	0.24	0.38	0.14	0.64	2.55	1.91

Table 5.3: Grain damage by chain conveyor, performance 12 t.h^{-1}
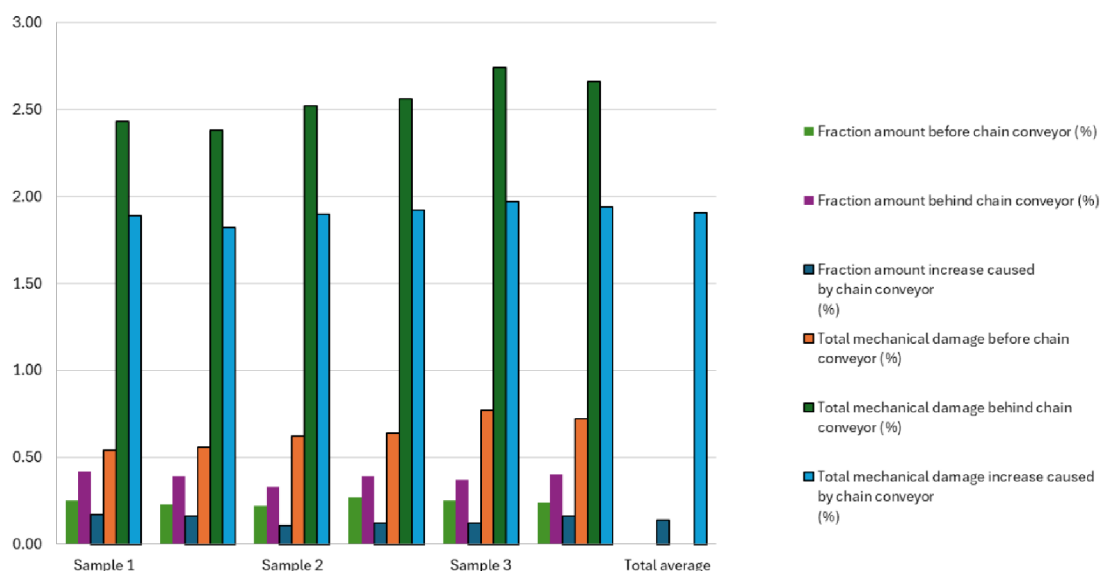
Fig 5.4: Grain damage by chain conveyor, performance 12 t.h^{-1}

5.2 Belt Conveyor

In a typical postharvest grain processing line located in the Central Bohemia region, belt conveyors are the most common conveyors. The observed conveyor is positioned between the receiving sub-level stack and the cleaning section, specifically for transporting received grain to pre-cleaning and sorting section and after this postharvest treatment toward tower storage units of the capacity 1 000 tons per each. The basic technical parameters of the belt conveyor are listed in table 5.4:

Performance (t.h^{-1})	Stable output (t.h^{-1})	Transport Distance (m)	Belt Width (cm)	Transport Belt Velocity (m.s^{-1})	Output (kW)
75	64	12	65	1.9	1.8

Table 5.4: Basic technical parameters of the belt conveyor

Sample Number	Crops	Volume weight (kg.hl⁻¹)	Grain moisture (%)	Fraction amount			Total mechanical damage		
				before belt conveyor (%)	behind belt conveyor (%)	increased by conveyor (%)	before conveyor (%)	behind conveyor (%)	increased by conveyor (%)
1	Julie	81.7	13.8	0.07	0.09	0.02	0.24	0.25	0.01
				0.01	0.03	0.02	0.20	0.22	0.02
2	Julie	81.8	13.9	0.02	0.06	0.04	0.26	0.29	0.03
				0.06	0.07	0.01	0.47	0.51	0.04
3	Julie	81.7	13.7	0.02	0.04	0.02	0.36	0.43	0.07
				0.08	0.10	0.02	0.42	0.47	0.05
Total average			13.80	0.04	0.07	0.02	0.33	0.36	0.04

Table 5.5: Grain damage by belt conveyor – horizontal transport, output 64 t.h⁻¹

Fig 5.5: Grain damage by belt conveyor – horizontal transport, output 64 t.h⁻¹

5.2.1 Belt conveyor parameters

Fig. 5.6 provides a schematic breakdown of the essential mechanical components within a typical belt conveyor system.

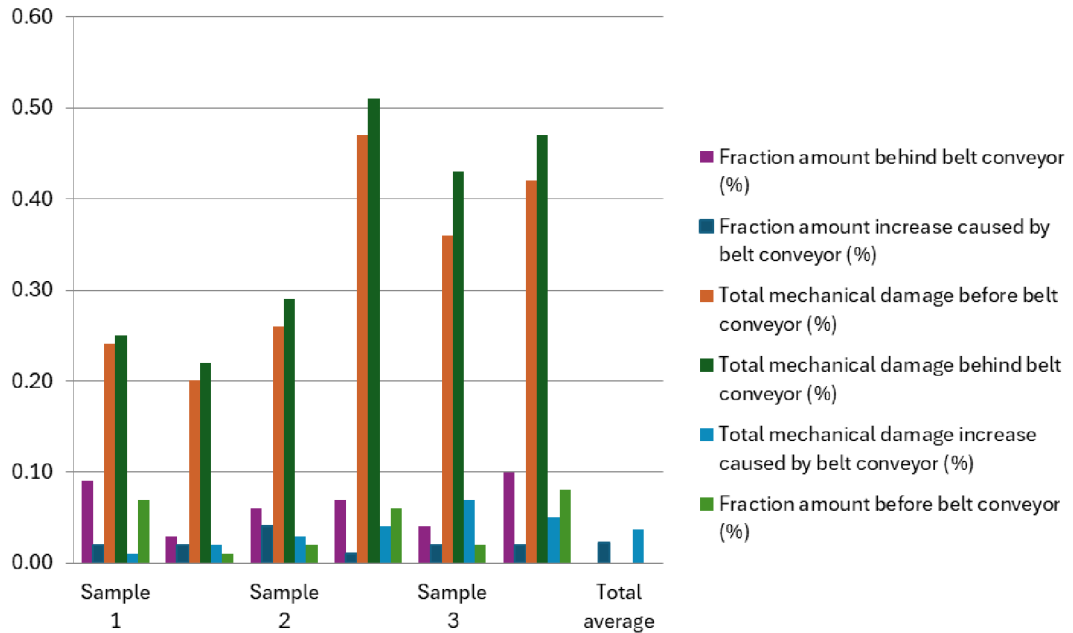Fig 5.6: schematic breakdown of the mechanical components within a typical belt conveyor - (1) Tail pulley (2) Snub pulley (at head-end and tail-end) (3) Internal belt cleaner (internal belt scraper) (4) Impact idlers ((impact rollers) (5) Return idlers (return rollers) (6) Belt (continuous loop of carrying run & return run) (7) Bend pulleys (8) Take-up pulley (9) Take-up unit (10) Carrying idlers (carrying rollers) (11) Pulley cleaner (pulley scraper) (12) External belt cleaner (external belt scraper) (13) Head pulley (normally this is discharge pulley and also drive pulley) (14) Feed chute (15) Skirt-board (Shah, K. P. 2018)

Based on the experimental results, and literature view, belt conveyors caused minimal grain damage during transport. So, in this section, the analysis of the conveyor is carried out on a selected belt conveyor with a transport distance of 15 m. The important parameters for the calculation are the transport efficiency Q_m [kg.s^{-1}] and the speed of the belt in [m.s^{-1}]. The traffic performance Q_m is usually determined by the operating conditions. In general, it can be calculated according to the formula:

$$Q_m = S * v * \rho_V * \psi_C \qquad (1)$$

where: Q_m - performance [kg.s^{-1}]

         S - cross-sectional area of the material on the conveyor belt [m^2]

         v - transport speed [m.s^{-1}]

         ρ_V - Density of the material [kg.m^{-3}]

         ψ_C - conveyor slope coefficient [-]

The calculation of the parameters of belt conveyors with rubber or PVC belts is carried out according to the ČSN 26 3102 standard. For the specified transport performance Q_m [kg.s^{-1}] and belt speeds in [m.s^{-1}], belt width B [m], circumferential force for conveyor drive F_O is calculated [N], the necessary power input of the conveyor P_d [W], the motor power of the drive unit P [W], the pulls in the belt and the size of the tensioning force F_N [N].

5.2.2 Calculation of belt width

The width of belt B is determined according to the used loading profile of the conveyor, where it is determined based on the cross-sectional area of the material on conveyor belt S. In this case, it is a three-roller stool. (Fig. 5.7)
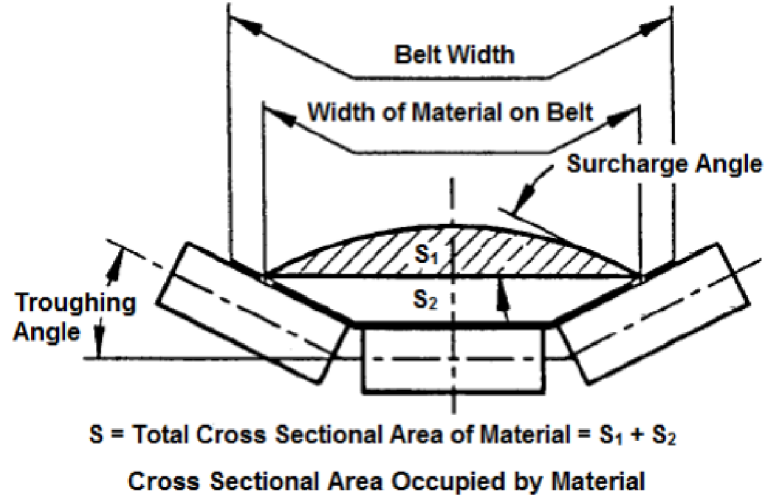

Fig 5.7: Conveyor with three-roll stool (Shah, K. P. 2018)

The cross-section is expressed as:

$$S = S_1 + S_2 \qquad (2)$$

$$S_1 = \frac{2}{3} * b_1 * h = 0.167 * b_1^2 * tg\,\beta \qquad (3)$$

$$S_2 = 0.25 * (b_1^2 - l^2) \qquad (4)$$

where: $b_1 = b * cos\,\alpha + l * (1 - cos\,\alpha)$ (5)

        b: used belt width [m],

        β: angle of inclination of the conveyed material [°]

The used loading width of the belt b is chosen within the limits:

For $B <= 400\ mm$: $b = 0.8\ B$ (6)

For $B > 400\ mm$: $b = 0.9\ B - 50\ mm$ (7)

So, the width of the band B can be expressed as:

$$B = \frac{b}{0.8} \qquad (8)$$

$$B = \frac{(b + 0.05)}{0.9} \qquad (9)$$

5.2.3 Calculation of circumferential force

The circuit force for driving the conveyor is given by the sum of all partial resistances of the loaded and unloaded branches. (ĎURKOVIČ, 1995)

The peripheral force F on the drive drum of the conveyor is determined according to the formula:

$$F = F_H + F_V + F_P \qquad (10)$$

where: F_H - main resistances to movement [N]
F_V - secondary resistances against movement [N]
F_P - additional resistances against movement [N]

F_H - the main resistances include pin friction in the roller bearings from the material load, the belt's own weight, and the weight of the rotating parts of the rollers.

F_V - secondary resistances include resistance in the hopper, bending of the belt over the drums, and pin friction in the bearings of non-driven drums.

F_P - additional resistances mainly include the force to lift the material to a height, the resistance of the belt cleaners, the resistance of the rakes, the resistance of the dropping cart, etc.

The peripheral force on the drive drum of the conveyor in the simplified calculation of secondary resistances to movement is calculated according to the following formula:

$$F_H + F_V = C * \mu * g * L * [(q_1 + 2 * q_2) * cos\,\delta + q_{rh} + q_{rd} \quad [N] \qquad (11)$$

where: C - coefficient respecting the length of the conveyor, used to calculate secondary resistances F_V [-]

μ - global friction factor [-]
g - gravitational acceleration [m.s^{-2}]
L - conveyor length [m]
q_1 - material weight per 1 bm strip [kg.m^{-1}]
q_2 - weight of 1 bm belt [kg.m^{-1}]
δ - angle of inclination of the conveyor [°]
q_{rd} - weight of the rotating rollers of the lower supporting stool [kg.m^{-1}]

Determining the weight of the material per 1 bm of strip length q_1 [kg.m^{-1}]

$$q_1 = \frac{Qm}{v} \qquad (12)$$

Determining the weight of 1 bm belt q_2 [kg.m^{-1}]

$$q_2 = B * m_p \qquad (13)$$

where: B - belt width [m]

   m_p - weight of 1 m² strip [kg.m⁻²]

Determining the weight of the rotating rollers of the lower support stool q_{RD} [kg.m⁻¹]

$q_{RD} = (m_{RD} * n_D) / L$ (14)

where: m_{RD} - roller weight [kg]

   n_D – number of rollers [pcs]

   L - conveyor length [m]

Calculation of additional resistances to movement:

$F_P = \varSigma F_{Pi}$ (15)

where: F_{Pi} - additional resistances against movement [N]

e.g.:   the force required to raise the material by the transport height, resistance of the material stacker, resistance of the dump truck, resistance of the belt cleaners, etc.

Secondary resistance forces are determined according to the formula:

$F_V = F_{V1} + F_{V2} + F_{V3}$ [N]   (16)

where: F_{V1} - resistance in the hopper [N]

   F_{V2} - resistance due to bending of the belt over the drums [N]

   F_{V3} - resistance due to pin friction in bearings of non-driven drums [N]

The proposed belt conveyor does not have a hopper, i.e. the resistance in the hopper is considered $F_{V1} = 0$ N.

The resistance due to the bending of the belt over the drums is calculated according to the formula:

$F_{V2} = 200 * z_B$ [N]   (17)

where: from z_B - number of drums [pcs]

The resistance due to pin friction in the bearings of non-driven drums is calculated according to the formula:

$F_{V3} = 150 * z_B$ [N]   (18)

where: from z_B - number of drums [pcs]

Table 5.6 shows the values that were inserted and calculated. Based on the resulting parameters, an optimal belt conveyor was selected to replace the chain conveyor located under the receiving basket at the selected agricultural cooperative.

Parameter	Mark	Unit	Value
conveying capacity	Q_m	$t.h^{-1}$	45
Belt speed	v	$m.s^{-1}$	1.1
Longitudinal inclination of the conveyor	α	°	0
The value of the factor taking into account the influence of the inclination of the conveyor	ψ_C	-	1
Specific volumetric weight of the material	ρ_V	$kg.hl^{-1}$	81.8
Pouring angle	β	°	21
Belt weight is considered	m_P	$kg.m^{-2}$	10.4
Cross-section of a layer of transported material	S	m^2	0.0195
Belt width	b	m	0.3
Waist width	B	m	0.35
The weight of the transported material on 1 m the conveyor	q_1	$kg.m^{-1}$	10.2
Belt weight 1m	q_2	$kg.m^{-1}$	2.2
Weight of the rotating rollers of the lower support stool	q_{rd}	$kg.m^{-1}$	2.9
The magnitude of the main drag force	F_H	N	7241
Resistance due to bending of the belt over the drums	F_{v2}	N	600
Resistance due to pin friction in non-driven drum bearings	F_{v3}	N	180
Secondary resistance forces	F_v	N	590

Table 5.6: Resulting values of the selected belt conveyor parameters

A new belt conveyor is to be installed under the receiving hopper. The conveyor must meet the following specifications:

- It must be able to convey material a distance of 16 meters.
- It must have a conveying capacity of 45 tons per hour.
- The conveyor belt must be 560 millimeters wide.
- The conveyor belt must travel at a speed of 1.1 meters per second.

Table 5.7 presents some belt conveyor producers and specifications of their products. There were three conveyor producers under investigation for specifications and price lists, GTK spol. s r.o, TRAMAZ a.s., and Skandia Elevator AB. Among which, by taking into account the results from this diploma thesis.

Belt conveyor technical specification:	Type 1	Type 2	Type 3
Conveyor Length	20 m	16 m	16 m
Transport Capacity (m3.h-1)	85 m3/h^{-1}	66 m3/h^{-1}	76 m3/h^{-1}
Roller Structure	Tubes Ø 57 x 5 mm	Tubes Ø 57 x 3 mm	Tubes Ø 57 x 3.2 mm
Belt type or material	EP 500/3 5+2	rubber	EP250/2 3+1,5 Y
Belt Width Vraity (mm)	500, 650, 800 and 1000 mm	400, 500, 600, 700, 800	400, 500, and 650, 800
Driving motion	Bevel gearboxes from leading manufacturers - SEW, Stiebel, Nord	Bevel gearboxes	Bevel gearboxes Nord
Maximal output (kW)	22-32	18-26	14-22
Feeding hopper (m)	1.6 m	1.5 m	1.5 m
Axial Width of Structure	698 mm	810	665
Outer Width of Structure	740 mm	870	700
Price (Approximately)	CZK 450000 (Including 21% VAT)	CZK 350000 (Including 21% VAT)	CZK 550000 (Including 21% VAT)
Producer Name	GTK spol. s r.o	TRAMAZ a.s.	Skandia Elevator AB
Produce Address	Tupesy 116, CZ - 687 08 Tupesy, Czech Republic	Kartouzská 4/200, 150 99 Praha 5, Czech Republic	Kedumsvägen 14 SE-534 94 Vara, Sweden

Table 5.7: Belt conveyors specifications and producers

6. Discussion

The diploma thesis results confirm that handling grain after harvest causes significant mechanical damage. Analysis reveals that grain handling during postharvest processing can cause significant mechanical damage. Chain and belt conveyors are the most widely used equipment for transporting grain within these processing lines (Patel et al. 2022). In grain storage systems, belt conveyors are the gentlest way to move grain horizontally. Chain conveyors are the preferred choice for high-capacity systems even though they can damage grain under heavy loads. This high amount of damage rates up to 2.63% grain breakage which is of a less concern compared to the grain damage that occur by loading the same conveyor at 25% of full capacity i.e. 4.6% (Mwaro et al. 2022). However, other common types of conveyors can damage the grain like bucket elevators pose a high risk of mechanical damage (Chen et al. 2020), while screw conveyors mainly break the delicate germs of the grains, especially those with enclosed troughs (Zareiforoush et al. 2010).

In this diploma thesis, the results revealed that the chain conveyor caused more damage to the grains in the postharvest line in comparison with the belt conveyor. Belt conveyor caused minimal total mechanical damage during grain transportation with a maximum amount of 0.07%. Similarly, with different types of crops, which was Brea, Kroupa achieved similar total mechanical damage 0.08% (Kroupa, 2003). This gentle handling makes the belt conveyor the ideal conveyor for horizontal grain movement within food grain processing facilities, particularly for reception, treatment, and storage lines.

Chain conveyor will cause the most significant grain damage when operating below their stable capacity. These damages likely occur at three points: during grain entry into the conveyor, during transport within the conveyor, and when exiting the conveyor. In this diploma thesis, total mechanical damage increased up to 1.97% while Kroupa achieved similar total mechanical damage with different type of crops, Alana, with a maximum amount of 1.98% (Kroupa, 2003). Mwaro similarly reported a grain breakage range of up to 2.63% during maize transportation with chain conveyor (Mwaro et al. 2022).

7. Conclusion

This diploma thesis on the topic "Maintaining quality parameters of agricultural grains during postharvest treatment and storage period" assesses the effect of postharvest operations, especially conveyors, on grain quality in a company located in the Central Bohemian Region. The theoretical part described the composition of the postharvest line, storage capacities, methods of transport and postharvest treatment. The goal was to determine the extent of damage on belt and chain conveyors in the practical part by working with the same variety of grain with a bulk density in the range of $81.7 - 82.3$ kg.hl^{-1} and a moisture content of 13.5% to 13.9%. A laboratory investigation involving three samples revealed that the prevalence of fragments on the belt conveyor ranged between 0.01% and 0.04%, while the incidence of total mechanical damage fell within a range of 0.01% to 0.07%.

Alternatively, the other results from similar tests for two different types of chain conveyors, revealed that when the chain conveyor is working below the stable output it will cause more damage to the grains. While the chain conveyor is operating at almost 50% of its full capacity, the amount of fragments was in the interval from 0.11% to 0.17% and the total mechanical damage was from 1.82% to 1.97%. On the other hand, the chain conveyor at its full capacity caused less damage and the amount of fragments was in the interval from 0.08% to 0.16 %. and the total mechanical damage was from 0.23% to 0.31%.

Based on these measurements, and theoretical research there could be done recommendation to use belt conveyor instead of chain conveyor in the chosen location in the postharvest line, due to its similar efficiency and small total mechanical damage that could cause. These results were confirmed in the diploma thesis by theoretical counting of the chosen belt conveyor. At the end of this diploma thesis, by the comparison of the properties and prices of the belt conveyors from three producers the belt conveyor from producer TRAMAZ a.s. is a proper replacement for chain conveyor which is beneath a 34-ton handling hopper.

The results only confirm the fact that even small reductions in grain damage caused by any type of conveyor are significant. Since grain undergoes multiple handling steps during postharvest processing, any accumulated damage can be substantial. Therefore, minimizing damage at each stage contributes to a higher overall yield and ultimately increases grain market production.

8. References

Abass, A.B.; Ndunguru, G.; Mamiro, P.; Alenkhe, B.; Mlingi, N.; Bekunda, M. Postharvest food losses in maize-based farming system of semi-arid savannah area of Tanzania. J. Stored Prod. Res. 2014, 57, 49–57.

Afzal, I., Bakhtavar, M. A., Ishfaq, M., Sagheer, M., & Baributsa, D. (2017). Maintaining dryness during storage contributes to higher maize seed quality. Journal of Stored Products Research, 72, 49-53.

AL-YAHYA, S.A. 2001. Effect of storage conditions on germination in wheat. J. Agron. Crop Sci. 186, 273–279.

Andrews, S. B., Siebenmorgen, T. J., Vories, E. D., & Lower, D. H. (1993). Effects of combine operating parameters on harvest loss and quality in rice. Transactions of the ASAE, 36, 1599e1607.

Angelovič, M., Krištof, K., Jobbágy, J., Findura, P., & Križan, M. (2018). The effect of conditions and storage time on the course of moisture and temperature of maize grains. In BIO web of conferences (Vol. 10, p. 02001). EDP Sciences.

Antoniak J. 1964: Obliczenia przenośników stosowanych w górnictwie. Wyd. Śląsk, Katowice.

AUMUND Group. (2024, January 4). AUMUND Group. https://www.aumund.com/

Baributsa, D., Njoroge, A.W., 2020. The use and profitability of hermetic technologies for grain storage among smallholder farmers in eastern Kenya. J. Stored Prod. Res. 87, 101618.

Befikadu, D. (2014). Factors affecting quality of grain stored in Ethiopian traditional storage structures and opportunities for improvement. International Journal of Sciences: Basic and Applied Research, 18(1), 235-257.

Borisow A.M. 1972: Issledowanija wertikalnych sznekowych transporterow. Trakt. i Siecchozmasz., 9, 25–27.

Bradna, J., Šimon, J., Hájek, D., & Vejchar, D. (2018). The impact of weather conditions on microclimate in storage facilities.

Brusewitz G.H., Persson S.P.E. 1969: Parametric study of factors influencing screw-conveyor throughput and power requirement. Trans. ASAE, 12, 1, 51–54, 59.

Capouchová I, Papoušková L, Hajšlová J, Prokinová E, Kostelanská M, Škeřiková A, Dvořáček V, Pazderů K, Faměra O. 2009. Risk of Fusarium infection occurrence for wheat baking quality. Úroda 12, 521 526 (in Czech).

Caughey, R. A., Tooles, C. W., & Scheer, A. C. (1951). Lateral and vertical pressure

of granular material in deep bins. Iowa State College of Agriculture and Mechanic Arts.

Cetiner, B., Acar, O., Kahraman, K., Sanal, T. & Koksel, H. 2017. An investigation on the effect of heat-moisture treatment on baking quality of wheat by using response surface methodology. Journal of Cereal Science 74, 103 111.

Channaiah, L. H., & Maier, D. E. (2014). Best stored maize management practices for the prevention of mycotoxin contamination. Mycotoxin reduction in grain chains, 78-88.

Chen, Z., Wassgren, C., & Ambrose, K. (2020). A review of grain kernel damage: Mechanisms, modeling, and testing procedures. Transactions of the ASABE, 63(2), 455-475.

Chigoverah, A.A.; Mvumi, B.M. Efficacy of metal silos and hermetic bags against stored-maize insect pests under simulated smallholder farmer conditions. J. Stored Prod. Res. 2016, 69, 179–189.

Christensen, C. M., & Kaufmann, H. H. (1969). Grain storage: The role of fungi in quality loss. U of Minnesota Press.

CIT VFU . https://cit.vfu.cz/

Cnossen, A. G., Jime´nez, M. J., & Siebenmorgen, T. J. (2003). Rice fissuring response to high drying and tempering temperatures. Journal of Food Engineering, 59, 61e69.

COMERTPAY, G., BALOCH, F.S., KILIAN, B., ULGER, A.C. and OZKAN, H. 2012. Diversity assessment of Turkish maize landraces based on fluorescent labeled SSR markers. Plant Mol. Biol. Rep. 30, 261–274.

Coradi, P.C., De Oliveira, M.B., De Oliveira Carneiro, L., Coelho de Souza, G.A., Elias, M.C., Brackmann, A., Teodoro, P.E., 2020. Technological and sustainable strategies for reducing losses and maintaining the quality of soybean grains in real production scale storage units. J. Stored Prod. Res. 87, 101624.

EPC (Engineering, Procurement, Construction). (n.d.). EPC (Engineering, Procurement, Construction). https://ivanemmoy.wordpress.com/

Da Silva, W.S.V., Vanier, N.L., Ziegler, V., De Oliveira, M., Guerra Dias, A.R., Elias, M.C., 2014. Effects of using Eolic exhausters as a complement to conventional aeration on the quality of rice stored in metal silos. J. Stored Prod. Res. 59, 76e81.

Demito, A., Ziegler, V., Goebel, J. T. S., Konopatzki, E. A., Coelho, S. R. M., & Elias, M. C. (2019). Effects of refrigeration on biochemical, digestibility, and technological parameters of carioca beans during storage. Journal of food biochemistry, 43(7), e12900.

Dincer, I. (2017). Refrigeration systems and applications. John Wiley & Sons.

Dmitrewski J. 1978: Teoria i konstrukcja maszyn rolniczych. T. 3. PWRiL, Warszawa.

Dreszer K. 1981: Badania przenośników ziarna w kombajnach zboŜowych. (Praca doktorska WTR–AR), Lublin.

Dreszer K., Gieroba J. 1984. Proces przemieszczania ziarna w przenośnikach śrubowych i zabierakowych. Problemy Agrofizyki 43, PAN, Ossolineum, Wrocław.

Dreszer, K., Pawáowski, T., & Zagajski, P. (2007). The process of grain relocation with screw conveyors. TEKA Kom. Mot. Energ. Roln, 7, 86-96.

Dreszer, K., Pawáowski, T., & Zagajski, P. (2007). The process of grain relocation with screw conveyors. TEKA Kom. Mot. Energ. Roln, 7, 86-96.

ĎURKOVIČ, Oto. Dopravní a manipulační stroje. 1995. ISBN 80-213-0134-1.

Fąfara R. 1967: Analiza pracy przenośników ślimakowych transportujących materiały łodygowe. Zesz. Probl. Post. Nauk Rol., 69, 121–162.

FAO (Food and Agriculture Organization), Mycotoxins in Grains. Available online: www.fao.org/Wairdocs/X5008E/X5008e00.htm#Contents (accessed on 7 January 2017).

FAO, 2013. Food wastage footprint: Impacts on natural resources.

FAO. (1997). Estimated postharvest losses of rice in Southeast Asia. Available at: <http://www.fao.org/News/FACTFILE/FF9712-E.HTM>

Ferreira, C.D., Ziegler, V., Lindemann, I.S., Hoffmann, J.F., Vanier, N.L., Oliveira, M., 2018. Quality of black beans as a function of long-term storage and moldy development: chemical and functional properties of flour and isolated protein. Food Chem. 246, 473e480.

Fleurat-Lessard, F. Integrated management of the risks of stored grain spoilage by seedborne fungi and contamination by storage mould mycotoxins—An update. J. Stored Prod. Res. 2017, 71, 22–40.

Fleurat-Lessard, F., 2017. Integrated management of the risks of stored grain spoilage by seedborne fungi and contamination by storage mold mycotoxins e an update. J. Stored Prod. Res. 71, 22e40.

Fourar-Belaifa, R., Fleurat-Lessard, F. & Bouznad, Z. 2011. A systemic approach to qualitative changes in the stored-wheat ecosystem: Prediction of deterioration risks in unsafe storage conditions in relation to relative humidity level, infestation by Sitophilus oryzae (L.), and wheat variety. Journal of Stored Products Research 47(1), 48 61.

Fruchtbaum, J. (1988). Bucket Elevators. In Bulk Materials Handling Handbook (pp. 77-137). Boston, MA: Springer US.

GADAG, R.N., JHA, S.K. and SINGH, A. 2006. Physical characteristics of different types of maize kernels. Maize Genet. Coop. News Lett. 80, 20–21.

Głozman W.M., Baitalski A.R., Kogan-Wołman G. 1979: Pieremieszczenie zierna spiralnymi konwierami. Mech. Elektr. Soc. Sielsk. Choz. 1, 20–22.

GOKALP, Z. and BUNDY, D.S. 2010. Analysis of lateral design pressures, vertical frictional forces and bending stresses on horizontal corrugated steel silo wall panels. Gaziosmanpas¸a Univ. J. Agric. Fac. 27, 71–79.

GONZÁLEZ-TORRALBA, J., ARAZURI, S., JARÉN, C. and ARREGUI, L.M. 2013. Influence of temperature and r.h.during storage on wheat bread making quality. J. Stored Prod. Res. 55, 134–144.

Govereh, J., Muchetu, R.G., Mvumi, B.M., Chuma, T., 2019. Analysis of distribution systems for supply of synthetic grain protectants to maize smallholder farmers in Zimbabwe: implications for hermetic grain storage bag distribution. J. Stored Prod. Res. 84, 101520.

Goździecki M., Świątkiewicz H.: 1975. Przenośniki. WNT, Warszawa.

Grolleaud, M. 1997. Postharvest Losses: Discovering the Full Story.

https://en.wikipedia.org/wiki/Chain_conveyor#:~:text=Chain%20conveyors%20are%20primarily%20used,friction%20pulls%20the%20load%20forward.

Gunal, A. K., Williams, E. J., & Sadakane, S. (1996, November). Modeling of chain conveyors and their equipment interfaces. In Proceedings of the 28th conference on Winter simulation (pp. 1107-1114).

Iguaz, A., Rodríguez, M., & Vírseda, P. (2006). Influence of handling and processing of rough rice on fissures and head rice yields. Journal of Food Engineering, 77(4), 803e809.

IST Surface Technologies. (2024, March 20). Home | IST International Surface Technologies. IST International Surface Technologies. https://istsurface.com/

Janczin S.K. 1969: O wlijani wieliczyny szaga chorizontalnogo sznieka na proizwoditelnost. Trakt. i Sielchozmasz. 4, 34–35.

Jansen&Heuning. (2024, March 11). Jansen&Heuning - Bulk Handling Systems. Jansen&Heuning. https://www.jh.nl/

Jayas, D.S., Jeyamkondan, S., 2002. PHdpostharvest technology. Biosyst. Eng. 82, 235e251.

JENIKE, A.W. 1964. Storage and flow of solids, Bulletin No. 123. Utah Engineering Experiment Station, University of Utah, Salt Lake City, UT, U.S.A.

Jia, C., Suna, D.W. & Caob, C. 2001. Computer simulation of temperature changes in a wheat storage bin. Journal of Stored Products Research 37, 165 177.

Jian, F., Narendran, R.B., Jayas, D.S., 2019. Segregation in stored grain bulks: kinematics, dynamics, mechanisms, and minimization e a review. J. Stored Prod. Res. 81, 11e21.

Kader, A. A. (2002). Postharvest technology of horticultural crops. University of California. Agriculture and Natural Resources, Publication, 3311, 535.

KARAOGLU, M.M., AYDENIZ, M., KOTANCILAR, H.G. and GERÇELASLAN, K.E. 2010. A comparison of the functional characteristics of wheat stored as grain with wheat stored in spike form. Int. J. Food Sci. Technol. 45, 38–47.

Kibar, H. (2015). Influence of storage conditions on the quality properties of wheat varieties. Journal of Stored Products Research, 62, 8-15.

Kibar, H. (2016). Determining the functional characteristics of wheat and corn grains depending on storage time and temperature. Journal of Food Processing and Preservation, 40(4), 749-759.

Kitinoja, L., & Gorny, J. R. (1999). Postharvest technology for small-scale produce marketers: economic opportunities, quality, and food safety. Postharvest technology for small-scale produce marketers: economic opportunities, quality, and food safety.,(21).

Klimowski Z. 1978: Uproszczona metoda obliczania wydajności pionowych przenośników ślimakowych. Czas. Tech., 6, 33–37.

Kold, J., & Silverman, C. (2016). Conveyors are used in the food industry. In the Handbook of hygiene control in the food industry (pp. 367-382). Woodhead Publishing.

Kroupa, P. (2003). The outer quality loss during grain post-harvest treatment and handling. Research in Agricultural Engineering, 49(3), 91-102.

Kumar, D., & Kalita, P. (2017). Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods, 6(1), 8.

Kumar, N. (2023). Fundamentals of conveyors. In Transporting operations of food materials within food factories (pp. 221-251). Woodhead Publishing.

Laszlo, R., & Adrian, T. (2009). Simulation of changes in a wheat storage bin regarding temperature. Analele Universităţii Din Oradea, Fascicula: Protecţia Mediului, 14(1), 239-244.

Lindemann, I.S., Lang, G.H., Ferreira, C.D., Colussi, R., Elias, M.C., Vanier, N.L., 2019. Cowpea storage under nitrogen-modified atmosphere at different temperatures: impact on grain structure, cooking quality, in vitro starch digestibility, and phenolic

extractability. J. Food Process. Preserv. 44, 14368.

Lopes, D.C., Martins, J.H., Castro Melo, E., Barros Monteiro, P.M., 2006. Aeration simulation of stored grain under variable air ambient conditions. Postharvest Biol. Technol. 42, 115e120.

Lopes, D.C., Steidle Neto, A.J., 2019. Effects of climate change on the aeration of stored beans in Minas Gerais State, Brazil. Biosyst. Eng. 188, 155e164.

Manandhar, A., Milindi, P., & Shah, A. (2018). An overview of the postharvest grain storage practices of smallholder farmers in developing countries. Agriculture, 8(4), 57.

MARKOWSKI, M., ZUK-GOŁASZEWSKAB, K. and KWIATKOWSKI, D. 2013. Influence of variety on selected physical and mechanical properties of wheat. Ind. Crops Prod. 47, 113–117.

Marks, B. P., & Stroshine, R. L. (1995). Effects of previous storage history, hybrid, and drying method on the storability of maize grain (corn). Journal of stored products Research, 31(4), 343-354.

MARTÍNEK, Václav a Pavel Filip. Mlynářská technologie 2: Skladování a příprava surovin [online]. 2012 [cit. 2023-01-28]. ISBN 978-80-239-9475-9.

Mlambo, S., Mvumi, B.M., Stathers, T., Mubayiwa, M., Nyabako, T., 2017. Field efficiency of hermetic and other maize grain storage options under smallholder farmer management. Crop Protect. 98, 198e210.

Mobolade, A.J., Bunindro, N., Sahoo, D., Rajashekar, Y., 2019. Traditional methods of food grains preservation and storage in Nigeria and India. Ann. Agric. Sci. 64, 195e205.

Mohapatra, D., Kumar, S., Kotwaliwale, N., Singh, K.K., 2017. Critical factors responsible for fungi growth in stored food grains and non-Chemical approaches for their control. Ind. Crop. Prod. 108, 162e182.

MOLENDA, M., HORABIK, J. and ROSS, I.J. 1998. Stress and deformation of wheat in direct shear test. Int. Agrophys. 12, 115–118.

Moncini, L., Simone, G., Romi, M., Cai, G., Guerriero, G., Whittaker, A., Benedetelli, S., Berni, R., 2020. Controlled nitrogen atmosphere for the preservation of functional molecules during silos storage: a case study using old Italian wheat cultivars. J. Stored Prod. Res. 88, 101638.

Mwaro, W. B., Maranga, S. M., Ikua, B. W., & Kanali, C. L. (2022, June). Establishing the amount of grain breakage taking place in bulk maize during conveyance through the drag chain conveyor. In Proceedings of the Sustainable Research and Innovation Conference (pp. 166-172).

NAVARRO, S., & Donahaye, E. STORAGE OF EWERGE~ NCY GRAIN

SUPPLIES. In paper presented at the Faculty Development Workshop on Issues in International Food Security, Colgate University. 2005

Navarro, S. Modified atmospheres for the control of stored-product insects and mites. In Insect Management for Food Storage and Processing; Elsevier: Amsterdam, The Netherlands, 2006; pp. 105–146.

Neme, K., & Mohammed, A. (2017). Mycotoxin occurrence in grains and the role of postharvest management as a mitigation strategy. A review. Food Control, 78, 412-425.

NZFMA. 2014. Wheat quality parameters. New Zealand Flour Millers Association, New Zealand.

Odjo, S., Burgueño, J., Rivers, A., & Verhulst, N. (2020). Hermetic storage technologies reduce maize pest damage in smallholder farming systems in Mexico. Journal of Stored Products Research, 88, 101664.

Paraginski, R.T., Vanier, N.L., Berrios, J.J., Oliveira, M., Elias, M.C., 2014. Physico-chemical and pasting properties of maize as affected by storage temperature. J. Stored Prod. Res. 59, 209e214.

Pedrick, C. Going to Waste—Missed Opportunities in the Battle to Improve Food Security, The Technical Centre for Agricultural and Rural Cooperation: Wageningen, The Netherlands, 2012.

Peter, B., Imoudu, A., & Olufayo, A. (2000). The effect of sun-drying on milling yield and quality of rice. Journal of Bioresource Technology, 74(3), 267e269.

POLAT, H.E. 2013. Integration of the effects of different storage types on nutritional quality characteristics of some feedstuffs. J. Food Agric. Environ. 11, 897–903.

Polišenska, I, Pfohl-Leszkowicz, A, Hadjeba, K, Dohnal, V, Jirsa, O, Denešova, O, Ježkova, A, & Macharačkova, P. 2010. Occurrence of ochratoxin A and citrinin in Czech cereals and comparison of two HPLC methods for ochratoxin A detection. Food Additives and Contaminants 27(11), 1545 1557.

PŠENICE OBECNÁ (Triticum aestivum L.) [online]. [cit. 2022-02-04]. Dostupné z: https://cit.vfu.cz/vegetabilie/plodiny/czech/psenice.htm

Rademacher F.J.C. 1981: On possible flow back in vertical screw conveyors for cohesionless granuelar materials. J. Agricult. Eng. Res., 26, 225–250.

REIMBERT, M. and REIMBERT, A. 1987. Design and calculation of the walls of horizontal silos (and retaining walls). Bulk Solids Handling 7, 561–571.

Römer G., Urban W. 1955: Die Förderung von Halmgut durch Förderschnecken. Landtechnik Forsch., 2, 48–52.

Rosentrater, K. A. (2022). Overview of storage systems for cereal grains and grain products. In Storage of Cereal Grains and Their Products (pp. 41-80). Woodhead Publishing.

Roy, P., Ijiri, T., Okadome, H., Nei, D., Nakamura, N., & Shiina, T. (2007). Effect of processing conditions on the energy consumption and quality of rice. ASAE Paper No. 076253.

Rupollo, G., Vanier, N.L., Zavareze, E.R., Oliveira, M., Pereira, J.M., Paraginski, R.T., Dias, A.R.G., Elias, M.C., 2011. Pasting, morphological, thermal and crystallinity properties of starch isolated from beans stored under different atmospheric conditions. Carbohydr. Polym. 86, 1403e1409.

Sadaka, S., & Rosentrater, K. A. (2019). Tips on Examining the Accuracy of On-Farm Grain Moisture Meters. Cooperative Extension Service, University of Arkansas.

SANTOS, S.B.D., MARTINS, M.A., FARONI, L.R.D. and BRITO JUNIOR, V.R.D. 2012. Dry matter loss in corn grains stored in airtight bags. Rev. Cien. Agronom. 43, 674–682.

SAWANT, A.A., PATIL, S.C., KALSE, S.B. and THAKOR, N.J. 2012. Effect of temperature, relative humidity, and moisture content on germination percentage of wheat stored in different storage structures. Agric. Eng. Int. CIGRE J. 14, 110–118.

Scariot, M.A., Radünz, L.L., Dionello, R.G., Toni, J.R., Mossi, A.J., Reichert Júnior, F.W., 2018. Quality of wheat grains harvested with different moisture contents and stored in hermetic and conventional system. J. Stored Prod. Res. 75, 29e34.

SEIFI, M.R. and ALIMARDANI, R. 2010. Comparison of moisture-dependent physical and mechanical properties of two varieties of corn (Sc 704 and Dc 370). Aust. J. Agric. Eng. 1, 170–178.

Shah, K. P. (2018). Construction and maintenance of belt conveyors for coal and bulk material handling plants. no. April, 1-269.

Siebenmorgen, T. J., Nehus, Z. T., & Archer, T. R. (1998). Milled rice breakage due to environmental conditions. Cereal Chemists, 75 (1), 149e152.

Siebenmorgen, T. J., Saleh, M. I., & Bautista, R. C. (2009). Milled rice fissure formation kinetics. Transactions of the ASABE, 52(3), 893-900.

SITUAČNÍ A VÝHLEDOVÁ ZPRÁVA OBILOVINY [online]. 2021, 1-113 [cit. 2022-02-04]. Dostupné z: https://eagri.cz/public/web/mze/zemedelstvi/publikace-a-dokumenty/situacni-a-vyhledove-zpravy/rostlinne-komodity/obiloviny/

Skalický, J., Kroupa, P., Bradna, J. & Pastorková, L. 2008. Ošetřování a skladování zrnin ve věžových a halových skladech. [Grain treatment and storage in tower silos and indoor storehouses]. 1. vyd. Praha: Výzkumný ústav zemědělské techniky, 80 pp.

Skocir, T. (2018). Mechanical conveyors: selection and operation. Routledge.

Smereczyński R. 1978: Teoria przemieszczania przenośnikami ślimakowymi itp. warunków. Mater. Kraj. Sympozjum „Kierunki rozwoju maszyn do zbioru zbóŜ i słomy", Wyd. Warszawa, 103–110.

TAFFAREL, C., RUFFATO, S., DANAO, M.G.C., NOGUEIRA, R.M. and ZANDONADI, R.S. 2013. Storage of corn in silo bag: Internal temperature profile and product quality. ASABE Annual International Meeting, 21–24 July 2013, Kansas City, MO, Paper Number: 131596115.

Tefera, T., Kanampiu, F., De Groote, H., Hellin, J., Mugo, S., Kimenju, S., Beyene, Y., Boddupalli, M.P., Shiferaw, B., Banziger, M., 2011. The metal silo: an effective grain storage technology for reducing postharvest insect and pathogen losses in maize while improving smallholder farmers' food security in developing countries. Crop Protect. 30, 240e245.

The Whole Grains Council. (n.d.). https://wholegrainscouncil.org/

Williams, S. B., Murdock, L. L., & Baributsa, D. (2017). Storage of maize in Purdue improved crop storage (PICS) bags. PLoS One, 12(1), e0168624.

Wiset, L., Srzednicki, G., Driscoll, R. H., Nimmuntavin, C., & Siwapornrak, P. (2001). Effects of high temperature drying on rice quality. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, 3, 1e10.

Woodcock, C. R., Mason, J. S., Woodcock, C. R., & Mason, J. S. (1987). Bucket elevators. Bulk Solids Handling: An Introduction to the Practice and Technology, 298-317.

Xihong, R.; Zhanggui, Q.; Yongjian, F.; Shuzhong, F.; Quan, L.; Jin, Z.; Liang, Q.; Liang, Y.; Tan, X.; Guan, L. Effects of oxygen concentration on the mortality of four adult stored-product insects in low dosage phosphine fumigation. In Proceedings of the 7th International Working Conference on Stored-Product Protection, Beijing, China, 14–19 October 1998; pp. 364–366.

Yang, W., Jia, C.C., Siebenmorgen, T.J., Howell, T.A. & Cnossen, A.G. 2002. Intra-kernel moisture responses of rice to drying and tempering treatments by finite element simulation. Transaction of the American Society of Agricultural and Biological Engineering 45(4), 1037 1044.

Yucel, C., BALOCH, F.S. and OZKAN, H. 2009. Genetic analysis of some physical properties of bread wheat grain (Triticum aestivum L. em Thell). Turk. J. Agric. For. 33, 525–535.

ZAALOUK, A.K. and ZABADY, F.I. 2009. Effect of moisture content on angle of

repose and friction coefficient of wheat grain. Misr. J. Agric. Eng. 26, 418–427.

Zareiforoush, H., Komarizadeh, M. H., & Alizadeh, M. R. (2010). Effect of crop-screw parameters on rough rice grain damage in handling with a horizontal screw conveyor. Journal of Food, Agriculture and Environment, 8(3-4), 494-499.

Zareiforoush, H., Komarizadeh, M. H., & Alizadeh, M. R. (2010). Effects of crop-machine variables on paddy grain damage during handling with an inclined screw auger. Biosystems engineering, 106(3), 234-242.

Zareiforoush, H., Komarizadeh, M. H., & Alizadeh, M. R. (2010). Effect of Screw Auger Rotational Speed on Paddy ('Oryza sativa'L.) Grains Damage in Handling Process. Australian Journal of Agricultural Engineering, 1(4), 136-140.

Ziegler, V., Paraginski, R. T., & Ferreira, C. D. (2021). Grain storage systems and effects of moisture, temperature, and time on grain quality-A review. Journal of Stored Products Research, 91, 101770.

Ziegler, V., Vanier, N.L., Ferreira, C.D., Paraginski, R.T., Monks, J.L.F., Elias, M., 2016. Changes in the bioactive compounds content of soybean as a function of grain moisture content and temperature during long-term storage. J. Food Sci. 81, 762e768.

9. Abbreviation Table

CZSO	Czech Statistical Office
FAO	Food and Agriculture Organization
MC	Moisture Content
NZFMA	New Zealand Financial Markets Association