Design and initial testing of a maize cob collection system

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Abstract: Maize cobs are valuable plant residues that can be used for many different purposes, including as a renewable energy source. Despite their value, maize cobs are still underutilized, mainly because people are not aware of their potential and harvesting techniques for their collection are still being developed. Therefore, this research focused on finding the most suitable energy- and time- efficient method for mechanical collection of maize cobs. Upgrading the combine harvester with an additional hopper proved to be the most promising solution, as it allows harvesting and storage of maize grain and maize cobs in one pass, while the harvesting time remains almost the same and the maize cobs are of good quality, as they do not fall on the field. A prototype with enlarged openings in the straw walkers, an additional grab container for maize cobs, a transport auger, a transport cleaning fan with built-in knives, a transport tube and some other assemblies was fabricated and used in practice. The first test results are very encouraging (94.4%-96.0% purity of maize cobs) and the system has been patented as a promising solution, especially in times when the environmental sustainability of the planet and energy independence are becoming increasingly important.

Keywords: maize cobs, utilization, mechanical harvesting, combine harvester upgrade
DOI: 10.25165/j.ijabe.20241703.8218

Citation: Dolšak B, Breznik A, Kaučič K, Imenšek N, Marčec M, Gselman P, et al. Design and initial testing of a maize cob collection system. Int J Agric & Biol Eng, 2024; 17(3): 108–114.

1 Introduction

Maize cob is a plant residue that usually remains unused in the fields after maize/corn harvest. It represents nearly 15%-20% of above ground non-grain maize residues with low bulk density/ specific weight. Maize cobs are known to be a material, composed mainly of cellulose (32.3%-45.6%), hemicellulose (39.8%) and lignin (6.7%-13.9%)[1,2], having thus woody structure. According to Brown et al.[3] and Kaliyan et al.[4] they are 46.6%-48.4% of carbon, 44.3%-45.5% oxygen, 5.6%-5.9% hydrogen and 0.3%-3.6% ash. However, according to some studies, the removal of cobs in their basic form from fields has little effect on the nutrient content of the soil. Moreover, the fertilization of fields where maize cobs were removed could be comparable to that of fields where cobs were not removed[5].

Because of the characteristics mentioned above, especially the low impact on the nutrient composition of the soil in their basic form and the simultaneously desirable physical and chemical properties, maize cobs began to be collected from the fields and used experimentally, initially as fuel for heating or drying grain. In the last decade, many studies have shown that maize cobs are a promising renewable energy source that can also be used as a feedstock for many different agrochemical and commercial applications/purposes. They can be for instance used as carriers for pesticides, fertilizer diluents, and fermentation substrates, in the production of activated carbon, lactic and oxalic acids, for asphalt shingles and roofing[6], as insulating and composite materials (chipboard)[7-9] and concrete additive[10], as raw material for the production of ethanol[11-14], succinic acid[12], furfural[15] and xylitol[14,16], as an absorbent for chemical wastes (removal of fluoride, zinc, nickel, endosulfan and dyes from water)[17-20], as a source of dietary fiber for feeding cows[21] and pigs[22], as a bedding material in broiler farming[23], as a repellents against mosquitoes[24], etc. However, this widely available biomass source is mainly used as a fuel for heating, grain drying and energy/electricity generation[25].

In order to be used directly or to allow longer storage for use in the above applications, maize cobs usually have to be dried. This is because, although they are the driest part of the maize plant when harvested, their moisture is still 20%-65%[26-28]. The relative yield of maize cobs depends on moisture content and is about 10%-20% of the grain yield[2,29,30]. According to Blandino et al.[31], with an average maize grain yield of 15 t/hm² (and a moisture content of 24.6%), an average maize cob yield of 3 t/hm² can be expected at a moisture content of 42%.

Considering their properties (yield, moisture, composition) and discovering their value, research began into methods of mechanically collecting maize cobs. In some developing countries, maize is still harvested by picker-husker or by manually picking the ears, so maize cobs are obtained by mechanical or manual shelling[32]. However, these traditional manual methods of harvesting

Received date: 2023-03-06 **Accepted date:** 2024-04-16

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maize and maize cobs are no longer widely used, while maize harvesting in developed countries is mostly done by universal combine harvesters with adapted working parameters[29]. In combination with these harvesters, it is possible to collect maize cobs from the ground after the maize grain harvest is completed or directly in the field at the same time that the maize grain harvest is taking place[32]. In addition, many new solutions have already been developed for collection and storage with prior separation of maize cobs from other maize residues using pneumatics, bounce plates and/or conveyor belts. Some of them were special devices towed by a tractor to pick up the maize cobs from the ground after maize grain harvest[33], while others were designed as carts towed by the combine, allowing the maize cobs to be picked up (and cleaned) directly as they felt their way out of the rear of the combine during maize harvest[34-39]. One of these[37] was the first commercially available maize cob harvester in 2008. A similar system, Hillco maize cob catching system, was developed for John Deere STS combines in 2010[40]. On the other hand, improved combines with pneumatic separation (of maize cobs and other residues) after straw walker with fan and unloading system[41,42] and modified axial flow combines[43,44] without additional hopper for maize cobs were developed, which in turn required the use of an additional cart (towed by a tractor or combine) during harvesting. The use of an additional cart and tractor requires more equipment and means more passes over the field, while the use of an additional cart in conjunction with the combine requires more complicated manoeuvring of the combine[42,45]. Therefore, new approaches to maize cobs harvesting have been developed, including modifications to an existing combine that allow simultaneous harvesting and storage of maize grain and maize cobs with one machine. For example, Bergonzoli et al.[32] developed an upgrade (modifications) for the rotary combine (axial flow) using the Harcob system - a combine equipped with a specific cob harvesting device, that includes a threshing and separation system, a cob hopper and an unloading device. On the other hand, Stukenholtz and Stukenholtz[45] focused on an upgrade for conventional (straw walker) combines, which are more common in Europe. However, the authors did not report on purity (ensuring that the maize husks are separated from the maize cobs), and efficiency, and did not answer the question of whether collecting the cobs (and emptying the hopper) interferes the harvesting of the maize grain. More recent publication on potential new devices for collecting maize cobs are not available. In general, there is a shortage of maize cob harvesters on the market. Moreover, the main disadvantages of those available are their low harvesting capacity and functionality (they still require additional trailers), etc. The new development in harvesting technology was believed to offer the possibility of collecting maize cobs as a by-product of maize grain harvesting without impurities and without additional costs, apart from the costs of adapting harvesting machines. For this reason, the aim of this work was to find the most suitable energy- and time-efficient design solution for mechanical collection of maize cobs, to fabricate the prototype of such solution, as well as to define its physical and operational characteristics in detail. The present solution could enable simplified and efficient collection of maize cobs as an important source of renewable energy, while reducing overall (including agricultural) dependence on fossil energy sources and providing an additional source of income for farmers (and others), while providing agricultural services.

2 Materials and methods

In order to find as many different solutions as possible for the mechanical collection of maize cobs a systematic approach was chosen for the investigation of the problem space and the search for constructive solutions, as prescribed in the guidelines for methodical development of solution principles[46]. After creating a list of requirements, a functional analysis was performed to decompose the main function (collecting maize cobs) into simpler sub functions, for which a variety of intuitive group methods were then used to find the most diverse solutions possible. The most promising of these solutions were then classified into a morphological matrix, based on which solution variants were generated.

Since collecting whole maize ears and separating the kernels from the cobs on the farm with a special shelling machine is known as less efficient and requires a lot of manual labor, this option was not included it in our study. Each of the two remaining options (collecting the maize cobs from the ground after the maize grain harvest is completed[33], and collecting the maize cobs directly in the field at the same time that the maize grain harvest is taking place) has its own advantages and disadvantages, which were considered in the design process and evaluated in more detail from both a technical and an economic perspective, with the energy and time efficiency of collecting the maize cobs as the main criteria.

The main advantage of picking up the maize cobs from the ground after the maize grains have been harvested is that the harvest of maize grain is not hindered by anything and can be done quickly and efficiently. A large and expensive machine (combine) can be moved to another location as quickly as possible, while the maize cobs can be picked up with a smaller and cheaper tractor attachment. However, collecting the maize cobs during a second visit to the field requires extra equipment, labour (time), more passes across the field and more energy[42]. In addition, the maize cobs picked up from the ground are usually of poorer quality, as many of them are damaged and contain many other unwanted contaminants such as other plants (weeds), mud, and stones, resulting in a higher ash content. Therefore, our research was oriented mainly on collecting maize cobs simultaneously with harvesting maize grain.

There are two possibilities to collect maize cobs during the harvest. The first option is to construct a special additional cart towed by the combine[34-39], while the second option is to upgrade the combine itself and add an additional hopper to it[32,42,44,45]. In both cases, maize cobs should be collected without falling on the ground to avoid unwanted contamination, resulting in better quality of maize cobs collected in this way. Combined harvesting of maize grain and maize cobs in one pass is also more energy and time efficient than harvesting in two passes, as explained above. However, possible slowdown of the combine harvest capacity due to towing of additional cart or additional emptying of the maize cob storage hopper can cause delays in maize grain harvest compared to option of harvesting maize grain only[47]. This has been the Achilles heel of this approach for many years. Producers saw maize cobs as low value compared to grain and, given weather and time constraints, were reluctant to develop the combines that could slow down maize grain harvest. However, considering the possibility of unloading maize grain and maize cobs at the same time and/or adjusting the size of the maize cob hopper to the size of the grain hopper while being able to manoeuvre easily, the combine upgrade proves to be the most promising, but also the most difficult in terms of meeting all the design criteria and specifications, of which we only list the most important ones:

1) Modifications to existing combine harvesters should be kept

in minimum, as they are generally difficult to implement.

2) An additional transport system and a full maize cob hopper represents significant additional weight that must be supported by the combine's basic structure. Moreover, the most unfavourable load case had to be considered when a filled hopper is emptying.

3) Quick mounting/dismounting of larger attachments that might be an obstacle when driving on public roads with the upgraded combine harvester, or when collecting maize cobs is out of the question because the combine harvester is being used to harvest other crops, needed to be made possible. Alternatively, in these cases, the additional hopper should at least be foldable. The possibility of unloading during harvesting was not considered because additional vehicle with trailer was needed.

4) In order to ensure smooth and efficient transfer of maize cobs from the hopper to the trailer positioned beside the combine harvester during field operations, initial specifications for the discharge point of the supplementary hopper were defined. These specifications dictate a height of 4.5 m from ground level and a horizontal distance of 3.5 m from the edge of the combine harvester.

5) Emptying the fully loaded maize cob hopper should take around 2 min to be efficiently harmonised with the time of emptying the main grain hopper on the selected combine harvester used in our experiment.

Taking into account all the requirements and constraints mentioned here, many different solution variants were developed, of which the combine upgrade turned out to be the most suitable. It was developed as prototype and tested in the field (harvest of three maize hybrids sown on four locations each) for its properties and efficiency. The weight of the maize cobs from each test field was determined with the Sigma 6ICB18 weighbridge (Libela Elsi, Slovenia), while the yield of the maize cobs was calculated from the weight data and the data from the combine harvester's digital data transfer system (telematics system), which continuously retrieves and records working data, including the harvested area, tracks and yield data. Due to the upgrade, the "yield sensors" were not yet installed in the additional hopper for maize cobs, so the yield of maize cobs had to be calculated. Subsequently, the husks and other impurities were manually separated from the maize cobs obtained, the impurities were weighed using the BA150C scale (Axis, Poland) and the purity of the cobs, i.e. the percentage of impurities as a measure of the cleaning performance of a system, was determined as the difference between the total weight (cobs + impurities) and the weight of the impurities. Husks, leaves, stalks, mud and grains were defined as impurities. Pure cobs were defined as whole and chopped maize cobs (including coarse and fine cob particles). The moisture content of pure maize cobs was determined with the Humimeter 1050 BMA (Schaller GMBH, Germany).

3 Results and discussion

3.1 Combine harvester upgrade design

The final design solution of this study is based on modifications to a Claas Tucano 340 combine harvester. This equipment already allows the separation of maize grain from cob, however, only grain is saved while cobs are left in the field as plant residue. Therefore, some changes and modifications were needed to enable additional collection of maize cobs.

The first step in designing the upgrade of combine was to incorporate all the additional systems properly into an already complex machine without hindering or even disabling the existing functions. The biggest additional element of the upgrade was the hopper, which should not only provide sufficient volume, but also be removable or at least foldable and allow efficient emptying.

The design considered the relocation of certain existing systems within the combine to ensure sufficient space for the installation a hopper on the combine. Some other existing structures within the combine harvester were also adjusted accordingly to ensure adequate additional cleaning of the maize cobs so that they could be properly separated from other lighter plant residues and transported to the storage hopper. All these adjustments on the selected combine harvester are described in more detail in the next section presenting prototype fabrication. Figure 1 shows a prototype of the maize cob hopper, showcasing folded side walls.

Figure 1 Prototype of the maize cob hopper

3.2 Prototype-properties and functionality

The design of the solution served as the basis for the development and fabrication of a prototype. Since the basic construction of the selected Claas Tucano 340 combine harvester was not suitable for implementing certain upgrades, some adjustments were required during the development and fabrication of the new prototype for reasons of safety, efficiency and feasibility.

Basic features of the prototype include the relocation of some existing assemblies on the combine itself to create space for the new hopper system at the rear of the combine. In addition, the air intake system is modified and moved slightly further to the front of the combine. The rear part of the machine is reinforced and the residue chopper is removed to make room for the new combine upgrade parts. The system inside the combine harvester is modified and upgraded. Straw walkers are modified (Figure 2), additional grab container and transport auger (Figure 3), transport cleaning fan with built-in knives, transport tube and some other assemblies are installed on the combine harvester.

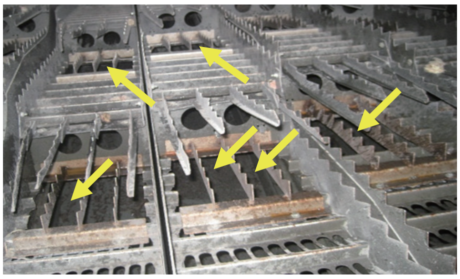
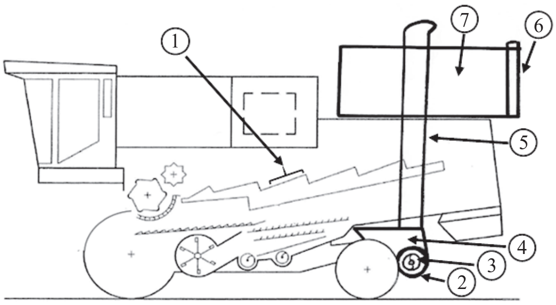


Figure 2 Adapted straw walkers with additional openings (marked with yellow arrows)

The process of collecting the maize cobs begins, as usual, with the transport of the maize ears (un-separated maize kernels and maize cobs) to the threshing drum, which separates the grain from the cobs. The majority of maize grain falls directly to the cleaning sieves, while maize cobs with impurities (husks) and some remaining maize grains continue its way to the modified straw walkers (Figure 2), which were formed by additional openings of 32 cm×6 cm in the basic straw walkers.

Similar openings (elongated slots) in sieves have also been described by other authors, but mainly for rotary combines[43,44]. In our system, these openings allow the maize cobs (and other impurities) to pass over a moving platform to the cleaning sieves. In this stage, husks and other light impurities are removed by existing built-in ventilation cleaning system, while maize grain falls through the sieve openings. On the other hand, maize cobs (whole or crushed) and materials that are too large to fall through the sieve openings but whose terminal velocity is greater than the velocity of the existing built-in ventilation cleaning system, are collected in a specially made grab container (Figure 4, position 4). Similar modified containers have also been used in systems by Johnson et al.[42] and Bergonzoli et al.[32]. Additional transport auger with a diameter of 250 mm is attached to the bottom of this container (Figure 4, position 3).

Figure 3 Assembly of additional cleaning fan, transport auger and grab container



1. Place, where additional openings in straw walkers were made, 2. Cleaning fan, 3. Transport auger, 4. Grab container, 5. Transport cleaning fan, 6. Chain conveyor, 7. Hopper for maize cobs

Figure 4 Scheme of maize cob combine

The auger transports the maize cobs to the additionally installed transport cleaning fan (Figure 4, position 2), which operates with an air flow of 9000 m^3/h. The turbine has built-in knives for cutting the cobs and at the same time transports the cobs through a special transport tube into the hopper (Figure 4, position 7). Knives are installed due to low average density of threshed wet maize cobs with the aim to minimize the frequency and costs of transportation.

The important part of the combine upgrade is also an additional hopper for maize cobs, which, albeit in different form, had already been used in other maize cobs harvesters (axial flow and conventional machines)[32,45]. A chain conveyor was added to the rear wall of the hopper, as rear loading with addition-al chain conveyor proved to be safer and more efficient than rear loading without using chain conveyor. This solution also reduced the load on the base structure, but at the same time required an additional hydraulic motor to drive the chain conveyor.

The design of the hopper also had to take into account that it must have sufficient capacity while meeting regulations for the permissible height and width for driving on roads. Therefore, divisible, hinged side walls were designed for the hopper, which can be opened (Figure 5a) and closed (Figure 5b) hydraulically. The hopper is emptied by means of hydraulic cylinders that tilt the hopper backwards (Figure 5c). During emptying, the weight of the maize cobs is helpful, because cobs move to the side of the hopper where a hydraulically driven chain conveyor is installed. The chain conveyor is activated when the hopper is emptying and helps move the cobs to the trailer or other transport vehicle. The emptying process must be performed with the combine harvester at a standstill. Despite the entire cleaning process, a small amount of husk remains between the cobs, but this also depends on the maize hybrid selected. According to the final virtual 3D model of the hopper, its netto volume is 7.5 m^3, which is slightly less than reported by Bergonzoli et al. (9 m^3)[32]. Based on the 3D model, the mass of the empty hopper is 1400 kg. Additionally, 7.5 m^3 of maize cobs with up to 40% moisture content (during prototype testing, the highest recorded moisture content was 39.1%), weights between 1300-2300 kg. Consequently, the maximum total mass of the full hopper is between 2700-3700 kg. This load was taken into account in the design of the supporting structure, considering the most unfavourable load case scenario in stress-strain analysis when the hopper is full and positioned at the extreme end over the trailer for unloading just before the start of emptying.

a. Closed position

b. Opened position

c. Emptying position

Figure 5 Maize cobs harvester with additional hopper built of divisible side walls in closed, opened, and emptying positions

Structural steel in sheet form was mainly used to upgrade the combine harvester with the maize cob harvester. Since the sole elements mounted on the combine harvester already represent a significant additional weight, alternative, lighter materials with sufficiently high load-bearing capacity should also be considered for series production of such an upgrade. According to our preliminary research, advanced cellular materials based on metal foams could also be considered for such an application[48].

Additional cameras are also installed for better and more effective control over the emptying and system operation. The entire operation can be monitored via the screen in the cabin.

The modified combine harvester is technically capable of unloading maize grain and maize cobs simultaneously while stationary. Therefore, if the maize grain is not unloaded on the fly during harvest, unloading the maize cobs does not extend the duration of harvest. However, due to complexity and better control, unloading the maize cobs is often done separately from unloading the grain. In this case, a few more minutes are required for unloading performance. During the testing of the prototype, the total emptying time of a full hopper ranged around two minutes, depending on the engine's RPM and the quality of the maize cobs. Thus, the condition we set at the beginning has been fulfilled. Nevertheless, the size of the maize cob hopper is adapted to the size of the grain hopper, so for every two emptying of the grain hopper, one emptying of the maize cob hopper is required.

The modified and upgraded maize cobs harvester described has been patented in Slovenia[49] and could also be used for commercial purposes. Such a solution (modifications) could also be implemented for other conventional combines (straw walker), while it is not acceptable for combines with rotary separation (axial flow). These machines do not have such a large rear section ("tail") to accommodate our system in its current configuration. However, as conventional combines are quite widespread in Slovenia and Europe, the proposed changes could significantly improve the operation of the combine, i.e. its multi-functionality.

3.3 Prototype testing

The trial harvest was carried out with three different maize hybrids sown in four fields (different locations in north-eastern Slovenia, but similar fertilization and planting patterns, i.e., maize plant population per hectare) in three consecutive years. Our results (Table 1) are in agreement with the data of other authors[50], who found that maize cob characteristics and consequently maize cob yield (as well as maize grain yield) are influenced not only by the selection of hybrids, but also by the location and year of planting, resulting in different soil properties and environmental influences (temperature, precipitation, etc.). In our study, the average moisture content of maize cobs at harvest ranged from 25.2% to 32.0% and was slightly lower than that of Bergonzoli et al.[32], who reported a moisture content of 32.1%. Moreover, the average yield of maize cobs (expressed at 12% moisture) in our study ranged from 1254 to 1772 kg/hm^2 (between 1902-2689 kg/hm^2 at 42% moisture), which is slightly lower than the value reported by some other authors[31] who assume an average maize cob yield of 3000 kg/hm^2 at 42% moisture. In Table 2, the results also indicate that the improvements at the combine proved to be suitable, as the average content of husks and other impurities at harvest ranged between 4.0%-5.6% (94.4%-96% purity) of the total yield of maize cobs. Our results are similar or even better than those of other authors who have determined the purity of maize cobs after harvesting with various invented machines. For example, authors who developed a cart towed by a combine reported purity of maize cobs between 89%-94%[38,39,51], while Smith et al.[41] used the improved combine to harvest maize cobs, also reported 94% purity. Although our other data (higher or similar average maize cob yield of the individual hybrids compared to previous years) could also be the result of site, weather and annual influences, and further improvements to the system are possible, the results indicate that the system has proven to be reliable and useful.

Table 1 Average maize cob yield for three consecutive years

Location	Maize hybrid	2019		2020		2021	
		Moisture[a]/ %	Yield[b]/ kg·hm^{-2}	Moisture[a]/ %	Yield[b]/ kg·hm^{-2}	Moisture[a]/ %	Yield[b]/ kg·hm^{-2}
Field 1	P9241	20.2	1617.8	31.7	1387.3	21.2	1634.3
Field 2	P9241	37.0	1121.1	29.6	1509.3	36.5	1493.4
Field 3	P9241	32.0	1315.5	24.3	1464.4	16.1	1085.2
Field 4	P9241	23.6	1481.1	28.9	1895.5	26.9	1582.0
Average		28.2	1383.9	28.6	1564.1	25.2	1448.7
Field 1	AJOVAN	27.0	1239.3	36.1	1143.3	21.0	1829.9
Field 2	AJOVAN	37.0	1287.2	28.3	1443.9	34.6	1636.8
Field 3	AJOVAN	29.3	1038.8	32.4	1377.3	14.5	1287.6
Field 4	AJOVAN	32.5	1451.3	31.0	1583.1	29.3	1554.6
Average		31.5	1254.1	32.0	1386.9	24.9	1577.2
Field 1	P9757	29.3	1792.4	26.0	1666.8	26.0	1884.4
Field 2	P9757	32.0	1605.7	21.4	2011.7	39.1	1537.6
Field 3	P9757	28.7	1748.4	35.5	1581.7	24.4	1695.7
Field 4	P9757	35.0	1363.5	26.8	1484.8	33.5	1972.7
Average		31.3	1627.5	27.4	1686.2	30.7	1772.6

Note: [a]Moisture level of maize cobs at harvest. [b]Expressed at 12% moisture level.

Table 2 The purity degree of maize cobs

Location	Maize hybrid	2019			2020			2021		
		Yield[c]	Impurities		Yield[c]	Impurities		Yield[c]	Impurities	
		kg	kg	%	kg	kg	%	kg	kg	%
Field 1	P9241	1784.0	77.4	4.3	1787.5	79.4	4.4	1825.7	78.6	4.3
Field 2	P9241	1566.0	80.4	5.1	1886.6	95.6	5.1	2068.8	107.5	5.2
Field 3	P9241	1702.4	70.2	4.1	1702.4	81.7	4.8	1138.3	53.8	4.7
Field 4	P9241	1706.0	73.8	4.3	2346.0	106.3	4.5	1903.2	77.4	4.1
Average		1689.6	75.5	4.5	1930.6	90.8	4.7	1734.0	79.3	4.6
Field 1	AJOWAN	1494.0	76.2	5.1	1574.6	87.3	5.5	2038.4	111.8	5.5
Field 2	AJOWAN	1798.0	88.4	4.9	1772.1	98.2	5.5	2200.8	100.4	4.6
Field 3	AJOWAN	1293.0	79.4	6.1	1793.0	101.9	5.7	1325.6	68.3	5.2
Field 4	AJOWAN	1892.0	91.4	4.8	2019.0	112.6	5.6	1935.7	91.4	4.7
Average		1619.2	83.9	5.2	1789.7	100.0	5.6	1875.1	93.0	5.0
Field 1	P9757	2231.0	92.3	4.1	1980.8	84.6	4.3	2239.4	96.3	4.3
Field 2	P9757	2078.0	80.3	3.9	2252.3	98.5	4.4	2221.9	100.6	4.5
Field 3	P9757	2158.0	84.2	3.9	2158.0	102.7	4.8	1972.5	88.7	4.5
Field 4	P9757	1846.0	74.3	4.0	1785.0	77.6	4.3	2610.6	114.8	4.4
Average		2078.2	82.8	4.0	2044.0	90.9	4.4	2261.1	100.1	4.4

Note: [c]Maize cobs with husks and other impurities, expressed as yield (fresh weight) per hectare.

4 Conclusions

Given the widespread and increasing use of maize cobs for various purposes in the world, including Europe, our aim was to develop a functional, effective and economically favourable mechanical method i.e. machine for their harvesting. Among the various ways of collecting maize cobs, the development of an adapted cereal harvester machine that allows simultaneous harvesting and storage of maize grain and maize cobs and does not hinder harvesting proved to be the most favourable solution.

The adaption and upgrade of the combine harvester included modifications of straw walkers, fabricating and installing additional grab container, transport auger, transport cleaning fan with built-in knives and transport tube. In addition, the upgraded combine includes additional hopper for storage of maize cobs, so that it does not require an additional cart. The system developed has many advantages, including the ability of unloading grain and cobs at the same time and simplified movement and transport compared to a combine that tows an extra cart. The main disadvantage is that it can only be used to collect maize grains and maize cobs. For the usual maize harvest, the system must be converted to its basic mode, which can be a disruptive factor, especially in the main harvesting season. Nevertheless, the advantages and functionality of the upgraded Claas Tucano 340 mechanical harvesting system with additional hopper for maize cobs outweigh the disadvantages and proved (average purity of maize cobs between 94.4% and 96.0%) to be a good solution for harvesting this widely available renewable energy source.

Acknowledgements

The authors gratefully acknowledge the financial support of the 16.5 EIP project "Maize Cob as a Renewable Energy Source" provided by the Ministry of Agriculture, Forestry and Food of the Republic of Slovenia as well as the financial support from the Slovenian Research Agency (Research Core Funding No. P2-0063). Thanks to the project partners for their cooperation and contribution. Thanks are also to the students of the Faculty of Mechanical Engineering of the University of Maribor for their contribution in the form of many valuable fresh design ideas and possible solutions to the challenge we faced in the early stages of this research.

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