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Evaluation of an Optical Sorter Effectiveness in Separating Maize Seeds Intended for Sowing

Dan Cujbescu [1], Florin Nenciu [1], Cătălin Persu [1], Iuliana Găgeanu [1], Gheorghe Gabriel [1], Nicolae-Valentin Vlăduț [1], Mihai Matache [1], Iulian Voicea [1], Augustina Pruteanu [1], Marcel Bularda [2,*], Gigel Paraschiv [3,*] and Sorin Petruț Boruz [4]

1 Testing Department, National Institute of Research—Development for Machines and Installations Designed for Agriculture and Food Industry—INMA, 013813 Bucharest, Romania; cujbescu@inma.ro (D.C.); florin.nenciu@inma.ro (F.N.); persu@inma.ro (C.P.); iulia.gageanu@inma.ro (I.G.); gabrielvalentinghe@yahoo.com (G.G.); vladut@inma.ro (N.-V.V.); matache@inma.ro (M.M.); voicea@inma.ro (I.V.); pruteanu@inma.ro (A.P.)

2 Department of Agronomy, Faculty of Engineering and Agronomy, Dunărea de Jos University of Galați, 800008 Galați, Romania

3 Department of Biotechnical Systems, National University of Science and Technology Polytechnica Bucharest, 060042 Bucharest, Romania

4 Faculty of Agronomy, University of Craiova, 200421 Craiova, Romania; sorin.boruz@edu.ucv.ro

* Correspondence: marcel.bularda@ugal.ro (M.B.); gigel.paraschiv@upb.ro (G.P.)

Abstract: The current study focuses on analyzing the impact of integrating an optical sorter in a seed-separation technological flow, in terms of increasing the quality of the maize seeds appropriate for sowing. The study showed that there are situations when the use of optical separation may result in a number of difficulties in removing a variable rate of good seeds from the raw mass, which can bring economic disadvantages. The identified issue encouraged the development of several flow assessment approaches in order to determine the problem's essence and to develop the best strategy for action. The key finding was that the evaluated optical sorting equipment cannot eliminate impurities without also removing good seeds, resulting in every 1% increase in impurity level and a rate of 0.70% of the good seeds lost. Therefore, farmers must carefully consider the scenarios where integrating optical sorting into their technological flow is a suitable option, considering the input material quality, the selling price of the product, and the risk of missing an important quantity of high-quality seeds. The working method described may be of significant importance to other farmers who intend to choose the components of grain-cleaning processes effectively.

Keywords: emerging technologies validation; optical sorter equipment; process efficiency; seed cleaning

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1. Introduction

Optical sorting is an emerging automated process for separating solid products using spectral cameras and lasers. Optical sorters may identify the color, size, form, structural characteristics, and chemical composition of an object depending on the types of sensors employed and the software-driven processing system. Optical sorting is one of the fields in which the most recent developments in artificial intelligence may be successfully used. The increasing spread of artificial intelligence applications, which may augment human and equipment capacities, is revolutionizing the production framework and task automation [1–4].

Testing and validation operations are essential components of all system engineering architectures. In the final phases of a complex technical flow design, the testing phases have the role to determine whether the quality requirements are met and whether installing additional components in the system is financially justified. Engineers are responsible for creating and building systems that are not only reliable but also flexible in response to changing demands. Technicians use a variety of methods and techniques, such as design matrices and constraint analysis, to build systems that satisfy the requirements of all stakeholders [5–7].

Certified seed production plays an extremely important role in obtaining increased quantities of fruits and vegetables and helps in the implementation of emerging agricultural technologies. This influence can determine an increase in the level of the agricultural harvest by up to 30%; therefore, seed production has received high research attention in recent years [8–10].

There are several factors that might affect agricultural crop production, starting with the influence of the planting material, culture technology, soil type, water availability, or phyto-sanitary treatments [11–13]. The careful selection of appropriate seedlings is one of the key factors in developing optimal growth of grain crops. To ensure that the crop has appropriate genetic features for a particular environment and use, the seeds must be selected for an appropriate genetic mix [14–16].

In the seed production activity, the professional requirements are higher, and the work technology is more demanding and requires more technical equipment [17]. The efficiency of seed production is conditioned by the existence of some technological links without which it is not possible to produce seed lots (irrigation, fertilization, and maintenance of crops through specific works (purified, etc.)). Thus, there is a need for technological discipline, professional training, and high-performance equipment [17,18]. Obtaining quality seeds and maintaining the initial characteristics of the variety or hybrid is performed according to special techniques, methods, scientific studies, and research [19–21].

The growing demands for modern agriculture, such as low input, high efficiency, and sustainable development, have made the transition to the concept of precision seeding systems [22–24]. Thus, the mechanization of agriculture has gradually transformed into "intelligent agriculture" as a result of advancements in agricultural science and technology. These concepts include novel agricultural machinery, the precise application of agricultural technologies, and improved management of agricultural production [25–28].

As maize seeds vary in size and shape depending on many factors, special batches of corn seeds are calibrated and labeled appropriately in order to achieve the highest level of seed uniformity [29–32]. However, the processing of seeds intended for planting includes a complex set of operations aimed at removing all impurities and non-compliant seeds, correcting humidity, sizing, grinding, dredging, chemical treatment, etc. These tasks are carried out by using improved machines and aggregates, grouped in installations that are currently called seed conditioning stations [33–37].

The complexity of the technological conditioning process is different from one station to another, which is determined by the degree of difficulty of cleaning certain seeds, as well as the requirements for their sowing [38]. The simplest processes are in the household-type stations, and the most complex in the corn drying and calibrating stations [39–41].

The density at sowing the hybridization lots was considered efficient in the past around the values of 65–70,000 plants·ha^{-1}; however, the current market trends encourage a higher sowing density. This can lead to quality problems, which may imply the need for further separation [42,43].

After harvesting, the seeds contain various impurities (minerals, organic residues, seeds of weeds and other cultivated plants, splinters, insects, etc.). The presence of these foreign bodies in the grain mass exerts a negative influence on the preservation of the products, diminishing the technical food value and the germinative properties of the seeds. In addition, some products contain toxic weed seeds or insects at different stages of development. In order to improve the purity of the products and create homogenous batches in terms of uniformity, the product mass has to be cleaned and sorted [44,45].

There are several technical solutions for sorting operations, such as mechanical, pneumatic, aerodynamic, and optical separation. In current agricultural practices, mechanical cleaning and sorting solutions have the greatest weight [46,47].

Cleaning represents the set of operations performed to remove impurities from the mass of products while sorting aims to separate the seed categories of size, shape, and color. That is why, in order to establish a technology for separating impurities, the physical-mechanical properties of both the basic product and the impurities were analyzed [48–50]. The most significant quality requirements regarding the purity and uniformity of the grains are met in the field of processing and obtaining seeds intended for sowing [51–54]. This fact is due to the need to perpetuate and use the biological value of a species (to obtain high production, special nutritional properties, and higher resistance to stress factors and diseases), and to create optimal conditions for sowing and sprouting (when the seeds are uniform, their phytosanitary status and germination are good, the seeders have a safer and more precise operation, the sprouting is uniform, the plants start growing simultaneously, and the differences in the level of development are small). In addition, the time needed for harvesting the fields is longer, which can reduce natural and artificial losses [55–60].

The aim of the current research was to determine the technological impact of an optical sorter on improving the quality of maize seeds destined for sowing. Therefore, the goal of the case study was to isolate the production flow's main challenges and implement the best corrective measures to minimize operating problems. The degree to which the contaminants may be reduced was determined using two different methods of testing. In this way, farmers will be able to select and effectively manage the technical elements of a grain-cleaning flow. The work approach described in this research, as well as the outcomes, may be of great interest for the implementation of separation technologies. The study also aims to address an issue that farmers typically do not anticipate, namely the possibility that a significant amount of high-quality seeds could be lost during the optical separation process.

2. Materials and Methods

2.1. The Considered Technological Flow and the Optical Sorting Equipment

The study was carried out at a farm producing cereals for planting material, located in Romania, Ilfov County. Tests were conducted using a known and controlled contamination level using several types of contaminants (other types of seeds such as sunflower seeds, soybean seeds, and damaged seeds). The process evaluation aimed at obtaining highly qualitative corn seeds intended for sowing and exploring the working environment of a medium-level breeding farm in Romania. The analyst's participation was necessary since the farm's technical flow had failed to produce the desired outcomes.

The technological flow adjustments were made by the farm technicians, with the exception of the optical sorter, whose adjustment was made by the representatives of the producing company.

The technological flow at the farm level is presented in Figure 1.

Commercial optical sorter equipment was used for the testing, which is highly specialized for grain separation. It uses advanced optical technology to sort the seeds and separate them according to their size, shape, color, and other physical attributes. According to the producers, the proposed technology was highly accurate and could detect even the smallest differences in the seed shape and size. The mass of seeds was guided by gravity in several troughs provided with flow channels, through which the total mass of material aligns, moves, and falls in front of the optical sorting system in the shape of a "canvas" or "curtain". The optical sorting system used optical cells to identify impurities and seeds that did not adhere to a pre-established color and formed standards set in the computer memory. The optical sorting system lighted the front and back of the material "canvas" and the material itself. The components in the seed mass that deviated from the "reference image" recorded in the computer's memory were detected by the optical system, and a jet of compressed air changed their fall trajectory.

The material removed from the flow is called "reject" in this paper, while the rest of the good seeds falling on a normal trajectory is called "accept". This process was controlled by specialized software that controlled the recording of falling material images and compared them with the preset standard images. The decision to blow the rejected seeds was very fast, and the working operations carried out by the machine could not be noticed by the human eye. In order to assess the effectiveness of the optical sorter integration in the flux, the working approach used was based on the knowledge of the raw material's quality.

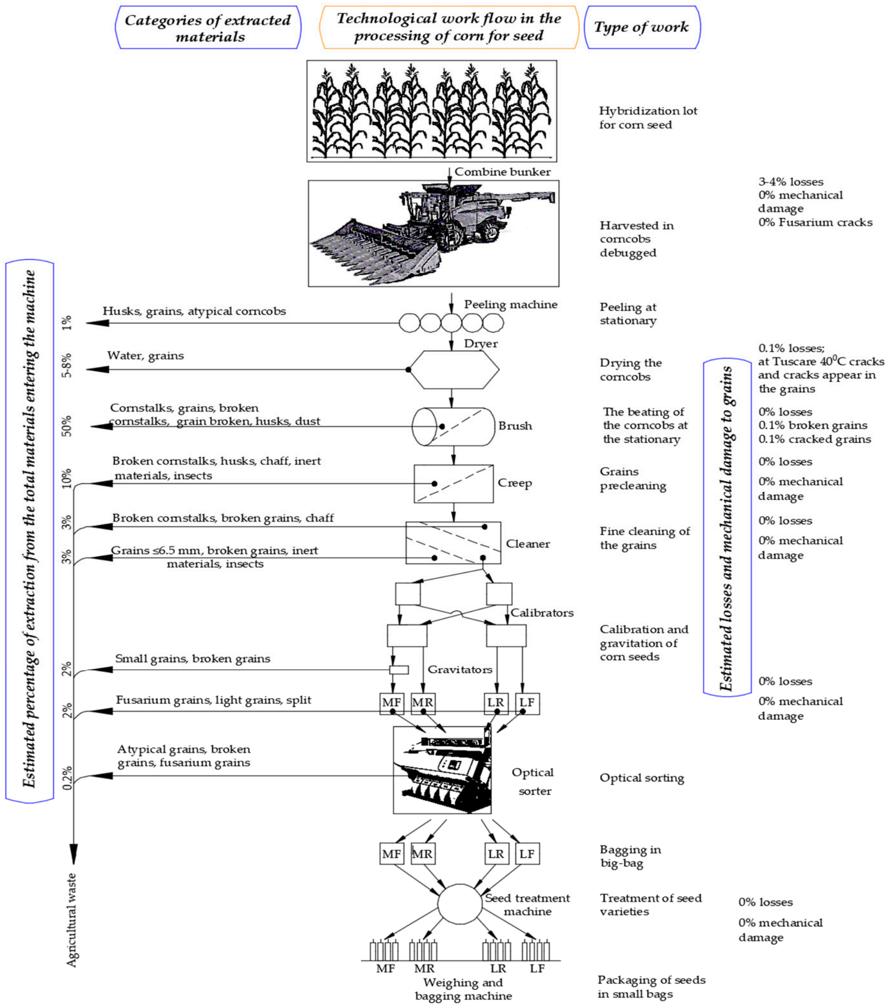

Figure 1. The technological flow considered in solving the problem.

2.2. Experimental Design

Two different methodologies were chosen to test the technological flow, which involved the controlled contamination of the seeds and the evaluation of the optical separation outcomes. The first approach consisted of feeding the sorter via an elevator in an indirect manner, whereas the second approach involved feeding the sorter directly.

The purpose of using a range of techniques was to precisely determine where the issue that resulted in the appearance of non-compliant outcomes occurred in the flow.

Independent and Direct Feeding of the Optical Sorter

In order to supply the processing flow with the raw material that needs to be processed, in the first experimental design, the seeds were lifted using an elevator and placed into a feeding container above the optical sorter at a height of 6 m. The optical sorter was placed at a height of 3 m above the ground to allow the gravitational capture in big-bags of the products coming out of the equipment. The following notations were used for the components that came out of the optical sorter: "accept" for the component that included the basic product, the useful part from the machine; "reject" for the component that included the impurities; "mechanical losses" for the material component that was created by the machine as a result of its operation; and "dust" for the component resulting from the pneumatic cleaning of the product being processed.

Two approaches were used simultaneously to analyze the quality of the work provided by the optical sorter:

1. The analysis was based on the sampling before the material entered the optical sorter for processing and from the machine output; by comparing them, the influence of the equipment on the product could be determined.
2. The analysis was conducted on the passage flow of a precisely known amount of an "artificial impurified" raw material. The level of contamination could be determined by weighing and comparing the influence of the machine on the mixture used.

The operations performed during the experiments consisted of the following:

- Filling the feeding basket of the sorting machine directly, with the help of the front loader.
- Carrying out the optical sorting operation and obtaining the output components based on the relating performed by the representative of the farm using corn seed from the OLT hybrid, LR caliber, and from the JOKARI CS hybrid, MR caliber.
- Weighing the input and output components in/out of the equipment and recording the data.
- Sampling, manual sorting by quality elements, and weighing the fractions for the application of the first verification method.
- Weighing artificial impurities before forming the mixture and manual sorting by sifting the product of artificial impurity from "reject"; collecting and weighing the mass of seeds in order to establish and separate the seeds for the application of the second verification method.

Figure 2 describes the seed separation installation for two different feeding methods: Figure 2a depicts the automated loading; Figure 2b shows the feeding process using a front loader; Figure 2c offers an in-depth perspective of the optical separation process.

(a) (b) (c)

Figure 2. Optical separation of corn seeds: (**a**) automated feeding using a vertical conveyor; (**b**) direct feeding with seeds using a front loader; (**c**) in-depth perspective of the optical separation process. The installation is composed of the following: 1—equipment supporting stand; 2—stiffening beams; 3—feeding stand; 4—vertical conveyor; 5—seed orientation pipe; 6—optical sorter feeding funnel; 7—optical sorter equipment; 8—funnel for big-bag loading; 9—big-bag for seed output; 10—power supply; 11—front loader; 12—big-bag for loading seeds directly using the front loader.

Figure 3 exemplifies three phases during the evaluation: Figure 3a is an image of the corn seeds impurified with sunflower and soybean seeds; Figure 3b depicts the manual verification of the separation efficiency; Figure 3c shows the seeds remaining after the separation.

(**a**) (**b**) (**c**)

Figure 3. Phases from the separation assessment: (**a**) corn seeds impurified with sunflower and soybean seeds; (**b**) manual verification of the separation efficiency; (**c**) seeds remaining after the separation.

The evaluation was carried out by taking 20 samples from each batch, which were weighed using an electronic precision scale (Partner, precision 0.5 kg).

In the context described above, the following aspects were considered:

- In the case of the first analysis method (by probing), samples were taken from the "basic material" being processed and then 30 samples were taken from the main sorts resulting from the processing, respectively from the "accept" and from "reject". The results obtained are of a nature to appreciate the quality of the materials from the three categories of products. A comparative analysis of the values showed the influence exerted by the machine during processing. The analysis was performed on the following elements of seed quality: good grains, broken grains, fusarium grains, grains with other defects, and mineral impurities. The data obtained for these indicators regarding the quality of the material used in the test (base material) and the data regarding the quality of the sorts resulting after processing (accept and reject) indicated, by comparison, the work performance of the optical sorter.
- In the second case, the artificial contamination method was used, in which a known amount of artificial impurified product was introduced (seed from another species of agricultural plants) into the working system of the machine) so that after the processing, this impurity could be manually extracted from the "reject" sort, where the workload was smaller. After weighing, this value indicated exactly how many artificial impurities the optical equipment managed to be removed in the "reject", and by comparing (from the total amount introduced into the system), the exact amount of artificial impurities remaining in the "accept" was obtained. In this working system, the sum of product inputs must be equal to the sum of product components leaving the machine. For artificial impurities, sunflower seeds and soybean seeds were used (soybean was closer to the color characteristics of corn seeds).

3. Results

For each quality parameter under study (good grains, broken grains, fusarium grains, grains with other defects, mineral impurities, and artificial impurities), quantitative measurements for both methods were conducted. Based on these measurements, a series of percentage and quantitative calculations for each parameter under study were then performed. In terms of the processed product, the working variants that were experimentally completed were as follows: V1—an artificially unpurified product; V2—an artificially impure product with sunflower; and V3—a deliberate impure product with soy and sunflower.

The results of the functional technical evaluation of the technological flow that integrated the optical sorter regarding the influence on the quality of the seeds by the "probing" method and by the "artificial impurity" method are presented below.

For the first case, regarding the indirect method of establishing the quality of the products, based on the samples taken and analyzed, the calculated data are presented in Table 1.

Table 1. The results obtained by testing using the indirect evaluation method.

Experimental Method	Product Quality Expressed as a Percentage for Different Categories												
	Total Raw Base Material (%) (100%)				Accept (%) (95.10%)				Reject (%) (4.87%)				
	Gs	Bs	Fs	Ai	Gs	Bs	Fs	Ai	Gs	Bs	Fs	Ai	D
V1	97.18	2.28	0.54	0.00	96.45	2.66	0.89	0.00	54.51	36.81	8.01	0.00	0.67
V2	96.45	2.66	0.89	0.92	96.50	2.61	0.88	0.01	67.12	13.39	3.67	15.67	0.15
V3	94.78	0.63	4.59	1.71 (sb 0.91% sf 0.80%)	95.07	0.18	3.91	0.84 (sb 0.84% sf 0.00%)	75.59	2.07	7.59	14.75 (sb 3.49% sf 11.26%)	0.0
Averagevalues	96.14	1.86	2.01	0.88	96.00	1.82	1.89	0.28	65.74	17.42	6.42	10.14	0.27

V1—uncontaminated product; V2—artificially contaminated product with sunflower seeds; V3—product artificially contaminated with soy and sunflower seeds; Gs—good seeds; Bs—broken seeds; Fs—seeds with fusarium; Ai—artificial impurities; D—mechanical losses and dust; sb—soybean seeds; sf—sunflower seeds.

- On average, from the material that is processed using the optical sorter, approx. 95.10% of the quantity reaches the "accept" output, whereas approx. 4.87% reaches the "reject" output, and a difference of up to 100% was reached by " mechanical losses" and "dust";
- The quality of the category "good grains" generally improves by about 0.14%, the quality of the category "broken grains" generally improves by about 0.04%, the quality of the category "fusarium grains" improves by about 0.12%, and the quality of the category "artificial impurities" improves by about 0.60%;
- The quantity of good seeds in the reject represents, on average, about 65.74% of the total quantity from the reject-box, and represents (on average) 3.27% of the total good grains entered for processing;
- If the impurity of the base material is higher, then the amount of good seeds in the reject-box is also higher (e.g., with an impurity of 2.82%, the share of good grains in the reject is 54.51%; at an impurity of 4.47%, the share of good grains in the reject is 67.12%; and at a 6.93% impurity, the share of good grains in the reject is 75.59%);
- Associated with the total good grains entered for processing, the amount of seeds found in the reject box will increase with an increase in contaminants (e.g., with an impurity of 2.82%, the loss of good grains in the reject is 1.34%; at 4.47% impurity, the loss of good grains in the reject is 3.97%; and at 6.93% impurity, the loss of good grains in the reject is 4.50%);
- The average value of the ratio of impurities in the base material/percentage of the extracted impurities is found to be 1:0.16;
- The average value of the ratio of impurities in the base material/percentage of good grains extracted and lost in the reject is 1:0.70.

The results obtained for the functional technical evaluation when integrating the optical sorter into the separation flow, using the "artificial impurity" method, are presented in Table 2.

- When using the first evaluation option, for determining artificial impurities based on sampling from the quantities entering and leaving the system, it was found to be less accurate than the second method for direct measurement (weighing) of artificial impurities entering and leaving the system;

- The total elimination (100%) of artificial sunflower impurities in the V2 evaluation option is explained by a measurement error since the scale where the samples were weighed had an accuracy of ±0.5 kg (see the values marked with * in Table 2);
- According to the data shown in Table 2, the soybean (which has a color closer to the color of corn) was eliminated in a proportion of 25.53%, whereas the sunflower which presents a better color contrast in relation to the color of corn was eliminated in a proportion of 97.32 ÷ 100%.

Table 2. The quality of the products (direct method (DM), using "artificial impurity" method).

Experimental Method	Artificial Impurities in the Base Material, %	Artificial Impurities Types, %	Extraction of Artificial Impurities Using the First Method, %	Extraction of Artificial Impurities Using the Second Method, %
V1	0.00	-	-	-
V2	0.92	100 (sunflower)	99.99	100 * from the total amount
V3	1.71	100% (53.42% soybean 46.58% sunflowers)	47.94 (21.31 from the total quantity of soybeans 78.49 from the total quantity of sunflowers)	58.96 (25.53 from the total quantity of soybeans 97.32 from the total quantity of sunflowers)

V1—non-artificially contaminated product; V2—product artificially contaminated with sunflower; V3—product artificially contaminated with soybean and sunflower; *—measurement error caused by the scale accuracy.

4. Discussion

The quality of the work performed by the optical sorter in the scenario under investigation can be assessed by comparing it with other sorters that operate according to other principles. In the case of aerodynamic or mechanical separation, for example, there are several options for controlling the operational processes to ensure that the primary product is not lost. The quality of the raw materials gained by calibration and gravitation in this instance allows for direct market sale of the seeds. That is why the expectations after the introduction of an optical sorter were very high. The farmers expected to increase the quality level without compromising the base material.

Recent studies on optical separation technologies are focused less on the separation of impurities and more on the detection of certain illnesses, determining certain resistant breeding lines, and the development of seedlings for use in new industries, such as suspended greenhouses [61–64]. A study that researched the optical removal of mycotoxin-contaminated kernels using a dual-wavelength high-speed commercial sorter [65] found that in the first pass through the sorter, aflatoxin was reduced by an average of 46%, and fumonisin was reduced by 57% while removing 4% to 9% of the corn. In the second pass of the accepted kernels, aflatoxin was reduced by 88% while removing approximately 13% of the corn. One study [66] obtained very good results for separating different corn varieties using optical sorting, showing that for this objective, optical separation could be the best technological solution. Other studies, which focused on the sorting of several types of wheat [67], showed separation results close to those found in the present research. For commercial sorters, more sorting indices have been developed as a result of the complexity of the sorting process and the development of various spectrum pretreatments, although many of them are not suitable for high-speed implementations.

The optical sorter tested in our study cannot remove impurities without removing good grains along with them. This is proven by the fact that when there are higher impurities (6.83% compared to 2.82%) from the rate of good seeds entering the processing, the percentage of good grains that are lost to rejection is higher (4.50% compared to 1.34%). As a result, the loss of useful grains may be a typical operational characteristic of the optical sorting technology that users should be aware of and accept; otherwise, it might seem to be a technical issue. For each increase in an impurity by 1% of the mass of seeds entering the optical sorter, there are 0.16% of extracted impurities, but 0.70% of good seeds are also lost as "reject".

This situation shows that the processing efficiency of the optical sorter is low for raw materials with a relatively high-quality level. The overall performance of the equipment is negatively impacted by the loss of high-quality seeds. At the same time, it should be noted that the value of the good grains lost by sending them to "refuse" represents a financial loss, considering the expense incurred for the production of the respective grains. This results in an increase in production costs while income decreases. Under these conditions, the profit is reduced by the increase in expenses on the one hand, but there is also a decrease in income on the other hand.

The goal of the current Romanian agricultural practice is to achieve an equilibrium where it is preferable to leave a small quantity of impurities unremoved rather than discard the useful product and incur financial losses. Moreover, in many cases, these impurities can be eliminated in the next stage of the technological flow.

The optical sorter is useful in all cases when the value of the main product lost by elimination to "refuse" is lower than the value created by increasing the quality of the processed seeds.

5. Conclusions

This study showed that there are situations in which the adoption of emerging tools in a seed separation technological flow may lead to a number of challenges. Although previous research has investigated the phenomena of losing some good seeds from the material, not many farmers have taken this element into account and are surprised by the high level of losses. The integration of an optical sorter into corn seed separation is beneficial only if the value of the primary product lost via elimination is smaller than the value gained by improving the quality of the processed seeds. However, there may be cases for different technological flows or for different varieties of corn where optical sorting could represent a solution.

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