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TECHNOLOGICAL INFORMATION

Development of a bulk cargo fruit sampler

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ABSTRACT. The design of an agricultural machine or equipment can be considered of great complexity, due to the interactions between the operator, the machine, the product and the environment. There is a lack of available technologies for collecting fruit in bulk cargo at any time from transport to industries. A limiting factor is the loading of fruits that are at the base of the cargo. This study was carried out to develop a fruit sampler for bulk cargo that can collect fruit in any position of the x, y and z axes. Methodology was divided into the following stages: design planning, informational design, conceptual design, preliminary design and detailed design. The variant considered the most appropriate was selected for the preliminary design and detailed design. The concepts were divided into chassis or support, sample collector and support for sample removal. The removal of fruits was carried out to maintain as much of their interaction with the environment outside the collector as possible. The equipment proved to be easy to assemble in the truck's bed. The samplers were all filled during harvest and were easily removed manually by the operators.

Keywords: Fruit sampler; design methodology; machine design; tomato transport.

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Introduction

Transportation, especially of fruit, in inappropriate vehicles results from the lack of specific legislation for the transport of perishable vegetable products in Brazil. Products are often transported in vehicles that do not have the minimum necessary conditions and without proper suspension for transporting sensitive products. The choice of the vehicle is based exclusively on the distance to be traveled, without considering its suitability for transporting the products, and there are still few studies on logistics of transport of agricultural products (Morais & Nascimento, 2019).

The consequences of this practice are cracked, crushed or severely injured fruits, to the point of disintegrating in the unloading operation in the industry (Santos, Ribeiro, & Colares-Santos, 2017). The transportation of fruits to the distributors or processing centers also causes severe damage to the transported cargo, especially when large stretches of unpaved roads or highways in a poor state of conservation are used, which requires technology for inspection, analysis of losses and improvement of transportation systems. Losses in the transportation of fruits such as tomato represent 5% of the total of 30% of losses in the entire post-harvest stage (Santos et al., 2017).

The growing investment in new technologies and equipment for agriculture has been applied throughout its production chain, from the planting of crops in the field to harvesting, transport and storage. Investment in such improvements brings numerous benefits to the producer, such as increasing the market value of the final product (Santos et al., 2017).

The creative capacity, associated with one or more methodologies for developing a design, aims to meet as much as possible the needs of users and designers, significantly reducing errors (Padilha, Carvalho, Mattos, & Gollo, 2010). The maximum return that an innovation can bring to users is the main objective of its development and will only be achieved with the help of the guidelines proposed by different methodologies (Grzebieluckas et al., 2011).

The methodologies for the development of agricultural machinery have design stages that can be divided into: design planning; informational design; conceptual design; preliminary design; detailed design;

preparation of production and product launch (Grupioni et al., 2018; Moreira, Teixeira, Fernandes, Cecon & Minette, 2013; Romano, 2013; Severo, Romano, Bender, & Boelter, 2014). On the other hand, Almeida, Conforto, Silva, and Amaral (2012) state that greater flexibility in design management provides greater conditions to obtain a more innovative product.

These methodologies apply to the design stages, to the known methods more appropriately and to the change from a qualitative to a more quantitative analysis. The use of these methodologies to develop machinery used for harvesting agricultural products has been shown to be effective (Grupioni et al., 2018; Moreira et al., 2013).

Not applying the knowledge on engineering and design methodology can result in errors in the design, in decision-making and even failures during the operation of prototypes. In addition, whenever the design results in a product, validations and tests either in the laboratory or in the field should be carried out to ensure that all design requirements are met (Mello, 2018).

In this study, a new technology is proposed for sampling fruit transported in road vehicles. The quality of the fruits will allow the accomplishment of researches and technical studies aiming to solve the problems associated with the transport and post-harvest physiology of the fruits. Therefore, using this technology, it will be possible to collect samples at any point inside the transport container (trailers, wagons, etc.) at any time during the distance covered.

In view of the above, the objective of this work was to develop a fruit sample collector transported in bulk loads so that fruits can be collected at any time during transport from the field to the industry.

Material and methods

The collector's design was developed using the methodology proposed by Pahl, Beitz, Feldhusen, and Grote (2005). The conception of the sample collector comprised a process that contemplates the confrontation of the tasks throughout the development of the design, aiming to obtain viable solutions, which resulted in a concept. At the end of each stage, there is a gain of information that feeds the next phase, and the design development stages are divided into: design planning, informational design, conceptual design, preliminary design and detailed design.

Design planning

Design planning consisted in defining a multidisciplinary design team, proposing the activities relevant to its development, An organization chart was created with the periods to execute the proposed activities and defining guidelines for determining the design requirements.

The team defined as a problem the collection of fruit samples in different positions in a trailer following criteria: the functionality of the design and the capacity to collect more than one sample per region analyzed. Areas planted with tomato crop for industrial processing were used as observation fields, and mechanized harvesting was being performed in these areas.

Informational design

The informational design stage is responsible for conducting the survey and treatment of customer requirements, creating a set of target specifications of the product, which served as the basis for decision making in the following steps (Grupioni et al., 2018; Moreira et al., 2013). It can be established that the main steps related to the informational design stage are:

- Conceptual design: should be carried out in as much detail as possible to create the first version of the equipment requirements
- Preliminary design: of the project structure and sampler drawings that will be useful
- Detailed design: quantity of materials and equipment assembly
- Usage performance: weaknesses and strengths in using the equipment

At the informational design stage, the requirements must be taken in quantitative and measurable values, because most of the time they are subjective (Carpes Júnior, 2011). The analysis of customer requirements is significant for the correct development of products, since the existence of any problem not defined or considered in the initial stages of the development of a design can generate losses, mainly due to the non-acceptance of the product by the market (Grupioni et al., 2018; Moreira et al., 2013).

The informational design basically consisted in researching about the state of technology in exhibitions, bulletins, catalogs, patents, among others. In addition, known technical systems were analyzed by observing similar competing and obsolete products. The concepts observed in the state of the art were taken into account in the next step, called conceptual design.

Conceptual design

After gathering the information from the previous stages, the Conceptual Design, began to be created based on the list of design requirements and on the construction of the morphological matrix, the chart of variants resulting from the interactions between the solutions and the valuation chart of the variants (Pahl et al., 2005).

By adapting the methodology proposed by Pahl et al. (2005), a simplified construction of a structure of functions was carried out with the creation of a morphological matrix. Specific subfunctions that the concept must have were created, so that it can achieve the objective proposed by the design team in the global function.

After generating the subfunctions and listing their various solving mechanisms, the solution or mechanism for each subfunction was chosen, resulting in a grouping called the solution variant.

The variants selected by the design team were evaluated to detail the positive and negative points of the solutions, considering the following criteria: low construction cost, low operation cost, total filling of the collector, easy installation and removal of the support and sample collector, interaction with fruits outside the collector, easy maintenance, high reliability, and parts of easy manufacture and replacement.

Preliminary design

The prototype architecture corresponding to the variant that obtained the highest score generated with the information from the previous stages was defined. Defining the concept of the sample collector served to understand the whole structural part, following the methodology used by Marini and Romano (2009). Computer-Aided Design (CAD) tools were used to understand the interactions between the constituent parts and also to improve constructive and dimensional aspects.

In this stage, the design was carried out according to technical criteria, and from this point on, the concept model evolved from conception to the definitive design of a product. It should be emphasized that the team was allowed to make justified changes in the design at any time.

Detailed design

The detailed design derives directly from the preliminary design, presenting the parts and assembly of the constituent elements of the concept. In addition, a simplified list of parts and materials, together with the cost, designation and reference of their components, was created.

The concept of the sample collector is then developed with the assignments of dimensions, dimensional tolerances, specification of joining materials and articulation of components. Finally, the team listed the materials to be used for constructing the collector.

Performance of use

Through the detailed design, a prototype was built and assembled under field conditions. The performance of use was observed regarding the ease of installing the equipment and removing the samplers.

Installation of the frame to then place the samplers, the filling of the samplers during the collection process and the removal of the samplers for the collection of samples were observed during the use of the equipment.

Results and discussion

Design planning

The first step was to define the work team, formed by academic professionals from the field of agricultural engineering, who later, together with producers, were able to define the harvest time of tomato fruits. After defining the harvest time, the team defined the collection points in each trailer used in the transport, following the orientation of the x, y and z axes.

Existing technologies were surveyed and analyzed and the minimum requirements for executing the design were defined. A weight was assigned to each evaluation criterion, according to the methodology used. After analyzing the evaluation criteria, the most appropriate variants for the design were chosen.

Informational design

The attributes selected by the design team that comprised the list of requirements for developing the sample collector concept were: geometry, transportation, installation, operation, use, maintenance, and costs.

To understand the purpose, after mechanical harvesting, the fruits were subjected to efforts that result in mechanical damage, whose effects are manifested mainly after the waiting time in the courtyard, arranged by order of arrival, which is necessary for water to drain from the trailers. However, it is at the time of unloading that the fruits suffer the greatest damage, due to the height of fall and, mainly, due to the excess load on them. A trailer used to transport tomato fruits in bulk has capacity for approximately 14 tons of product. However, cargoes can arrive at the industry, even after drainage, with a surplus of up to 4 tons.

Sample collectors are used for various types of products and assist in checking the quality of the product being delivered. In the agricultural sector, they are mainly used in storage warehouses or in agroindustry. The samples are composed of the material collected throughout the container where the cargo is located, thus giving greater reliability regarding the state of the product. Such samples can be used for physical-chemical evaluations of the state of the product during transport. In addition to collection via specific instruments, samples can also be collected manually (Fisher et al., 2011; Câmara, Gomes, Matuk, & Szarfarc, 2014).

There are some sample collectors for bulk cargoes on the market. Most collectors were developed for the collection of cereal samples. Systems developed for grains can be manual, pneumatic or automated. These systems are generally invasive and are usually located in warehouses.

Patent application proposed by Kaufmann (2009), refers to a constructive arrangement applied to a manual sample collector for cereals, known as a ‘calador’. The manual ‘calador’ has an innovative shape with regard to its inner tube, which has the internal openings distributed helically along the length of the tube, thus openings are closed gradually, in order to minimize the effort of the operator during grain cutting. The bulk cargo fruit sampler acts differently at the time of collection, as it is installed in the transport container, with no need for invasive sampling in the cargo, which could cause damage to the collected samples.

Patent application proposed by Maion (1990), refers to a fruit sample collector that performs random collection at any point of the cargo, not allowing the person responsible for the cargo to know beforehand the place or point of the cargo to be sampled. The device has a tubular body with diameter suitable for the collected fruits and a length substantially compatible with the height of the transport truck trailer, and the tubular body has a flipping lid at its lower end. The lid can be displaced angularly within a 180º range, with a locking device at the lower end, which has the lid in an almost horizontal plane. A drive lever acts on the lid, or hatch, which is pulled by an elastic ring tied to the tubular body.

The collector is mounted on an electric hoist, suspended by cables, so it is not portable, which prevents the collection of samples during the trip from the field to the industry. Another factor analyzed was the way of obtaining the samples; the collector is inserted into the cargo in an invasive manner, compromising the integrity of some fruits, especially those that are in contact with the tube walls. The sample collection height can be regulated by the hoist cables and, according to the need, it is possible access any point of the cargo. However, in the unloading of the samples inside the collector there is no precision about the height of the cargo at which each fruit was collected, as the fruits are mixed inside the samples.

In order to understand the influence of transport on the physiological response of fruits, Pérez López et al. (2014) developed a portable prototype that applies the load directly on the fruit and measures respiration through a continuous airflow system. The load application system consists of a two-inch steel tube, suspended with free movement, through which weights were placed to vary the loads on the fruits. The bottom of the tube was fixed to a piece of wood with 19 cm diameter, whose function is to apply the load directly on the fruits. Just above the weights, an accelerometer was installed, positioned in such a way that the “x” axis coincided with the forward direction of the vehicle, “y” coincided with the lateral movements and “z” coincided with the values of vertical force.

In this system, the fruits can be collected and evaluated for their physiological damage at any stage of transport from the field to the industry. However, its use consists only of a simulation of the load on the fruits (represented by the weights), which does not represent the forces to which the fruits are subjected at different load levels that can be analyzed.

The works presented above helped in the construction of the bulk fruit sampler due to its construction mode and action in agricultural loads. Some particularities had to be adapted in the equipment due to the characteristics of the tomato fruits and the transport containers and the possibility of different times of removal.

Conceptual design

In the conceptual design, the design requirements were listed, based on the stages of information, definition, creation, evaluation and decision, in which the questions were answered as to the purpose that the proposed solution had to satisfy and what characteristics it should have (Pahl et al., 2005).

The list of requirements presented in Table 1 was formulated by establishing the needs and requirements that the concept of the sample collector must have when it is completed, disregarding the criticisms with respect to technical or economic feasibility.

Table 1. List of requirements for the sample collector.

Workshop	Requirements	
R/W*	Geometry: dimensions	
	Support Structure	Sample Collector
R	Length ⩾ 3m	Height ⩽ 1.70 m
R	Width ⩾ 1m	Empty weight ⩾ 2 Kg
R	Mass ⩾ 15 kg	Full weight ⩾ 30 kg
	Fixation	
	Support Structure	Sample Collector
W	Non-fixed support	Non-fixed supports
R	Bolt and nut	
	Collector filling	
	Moment	Mode
R	Before harvest	Manual
W	During harvest	Mechanical
R	After harvest	
	Removal of sample collector	
R	Manual	
W	Hydraulic	
R	Ropes and pulleys	
	Use and maintenance	
W	Free of constant maintenance: robust parts.	
R	Parts subject to wear: simple and as few as possible.	
R	Parts resistant to: dust and solar incidence (or with adequate treatment to withstand such conditions).	
	Costs	
R	Minimum cost of manufacture: parts, production processes and outsourced labor with cost below R$15,000.00.	
R	Use of materials with easy acquisition: available in the market.	

*R = Requirements; W = Wishes.

Among the requirements selected for the sample collector concept, the collection parameters must be possible at any time of transport; low cost to produce the device; and use of easily acquired parts and mechanisms or widely used in the market

Subsequently, the morphological matrix (Table 2) was created from the combination of the solutions for each subfunction considered. The combination of subfunctions generated different variants or concepts. The solutions were arranged through sketches, in order to promote the evaluation of the combinations. With the combinations between the solutions of the subfunctions, the variants were listed, in a total of 729 possible variants.

Table 2. Morphological matrix of subfunctions and solutions.

Subfunction	Solutions		
	1	2	3
Structural	Cylindrical	Conical	In boxes
Support	On floor	On edges	Without structures
Fruit entry	From above	Inside the cargo	Boxes at different heights
Fruit holding	Flexible material	Rigid trailers at levels	Loose in boxes
Fruit removal	Manual	Pneumatic (Negative pressure)	Mechanical
Collector removal	Industry	After unloading	At any moment

From the total number of variants, five viable solutions were selected by the design team (Table 3) to be evaluated for the detailing and valuation of the positive and negative points of the proposed solutions.

Table 3. Selection of variants resulting from morphological matrix combinations

Variants of solution	Structure	Support	Fruit entry	Fruit holding	Fruit removal	Collector removal
38	Cylindrical	On floor	Inside the cargo	Rigid trailer without level	Manual	After unloading
205	Cylindrical	External structure	Hatch	Rigid trailer at level	Mechanical	Industry
327	Conical	Internal structure	Surface	Flexible material	Manual	At any moment
444	Conical	External structure	Hatch	Trailer without level	Manual	At any moment
567	Boxes	On floor	Boxes without level	Loose in boxes	Mechanical	At any moment

After selecting some of the variants, scores (from 0 to 5) and weights began to be assigned (Table 4).

It was possible to observe that variant 327 had the highest score, 4.24, among the variants evaluated. For this reason, it was selected for the preliminary design and detailed design steps. This variant has a surface structure that allows it to be mounted at the same level as the trailer. Its low manufacturing cost can be attributed to the few parts to be assembled and the cost of the flexible material, which also contributes to an easy operation and assembly of the device.

Table 4. Variants with the sum of the values of scores, after weighting by the evaluation criteria

Evaluation criteria	weight	Variants of solution									
		38		205		327		444		567	
		Value	Value x Weight	Value	Value x Weight	Value	Value x Weight	Value	Value x Weight	Value	Value x Weight
Manufacture cost	0.06	4	0.24	3	0.18	4	0.24	4	0.24	4	0.24
Operation cost	0.06	4	0.24	4	0.24	5	0.30	4	0.24	4	0.24
Transport	0.08	5	0.40	4	0.32	4	0.42	5	0.40	5	0.40
Fruit entry	0.20	3	0.60	5	1.00	4	0.80	4	0.80	4	0.80
Assembly	0.16	4	0.64	4	0.64	5	0.80	5	0.80	5	0.80
Collection operation	0.20	5	1.00	5	1.00	4	0.80	4	0.80	4	0.80
Maintenance	0.16	5	0.64	4	0.64	4	0.64	3	0.48	3	0.48
Manufacture, assembly and replacement	0.08	4	0.32	4	0.32	4	0.24	4	0.32	3	0.24
Total	1	4.08		4.02		4.24		4.08		4.00	

The fruits enter by the upper opening, thus making the collector able to receive fruits at the time of harvest or manually. The number of parts developed for this collector makes it easy to transport and maintain.

The collection operation is the responsibility of the people in charge of removing the collector from the holder, an operation that can be performed by only one person, depending on the weight of the collector when full.

Preliminary design

At this stage it was defined that the concept of the sample collector prototype would be divided into two parts: chassis and fruit sampler container. The chassis was constructed with steel profiles that form the longitudinal (1) and transverse (2) bars, joined by means of nuts and bolts (Figure 1).

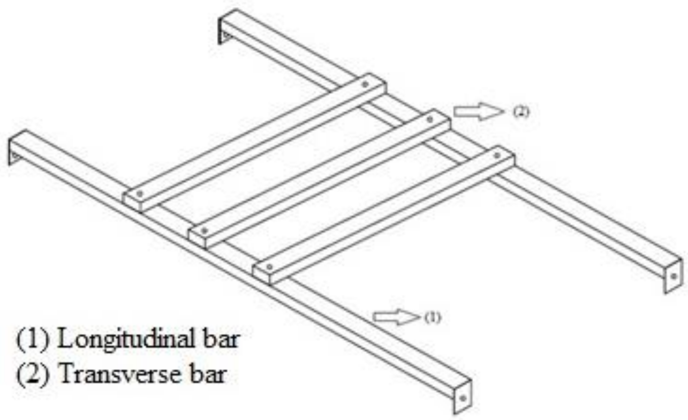

Figure 1. Structural elements of the chassis, in the design of the bulk cargo fruit sampler.

Each longitudinal profile has its measurement according to the width of the transport container. The transverse bars are made with the same material as the longitudinal bars and can vary in quantity according to the number of sample-collecting containers. For the union between the bars, bolts were placed at the end of the transverse bars and at any point of the longitudinal bars. At the ends of each longitudinal bar, there are steel plates to assist the fixation of the chassis to the transport container.

Figure 2 shows the elements that comprised the fruit sampler container.

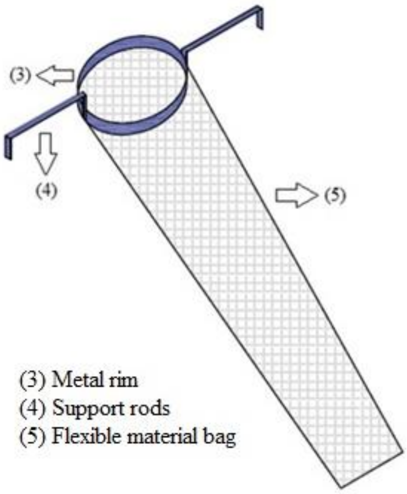

Figure 2. Elements of the bulk cargo fruit sampler container.

The collector container consists of a steel rim (3), steel plates as support rods (4) and a flexible material bag (5). The rim (3) has an internal area of circumference corresponding to the entry of five fruits of the harvested crop being loaded at the same time. Its sides are joined with the support rods (4), which can vary in size according to the distance between the transverse bars (2) of the chassis. The rim (3) is covered by the flexible material bag (5). Each bag (5) has the same area of the rim in its upper end (3); its body is tapered in shape, for a better removal of the cargo collector container, and its height is based on the height of the container where the fruits will be transported.

Detailed design

Table 5 shows a simplified list of materials and parts, and the costs, in US$, referring to the concept of the developed sample collector. The cost of production of a sample collector was expressed in U.S. commercial dollar, official currency of the Central Bank of Brazil (PTAX 800). The price of the foreign currency, measured in units and fractions of the national currency, in the amount of R$ 5.18 (21/10/2022) was considered as the exchange rate. The total cost of materials to construct the collector was US$ 111.34. Of this value, 53.13% was allocated to the construction of the chassis, 17.84% to the manufacture of sample collectors, and 29.03% to the manufacture of the supports to hold the collectors.

Table 5. List of parts and their approximate costs in US$

Description	Quantity	Unit	Unit cost (US$)	Total cost (US$)
75 mm x 40 mm U-shaped steel profile	9.70	Meter	4.99	48.37
50 mm x 30 mm rectangular steel profile	14.00	Meter	1.55	21.70
1” x 3/16” steel plate	9.50	Meter	1.58	22.05
4” x 3” x 5/16” steel plate	4.00	Unit	1.42	5.68
2” x 7/16” bolt	6.00	Unit	0.67	6.33
2” x ½” bolt	4.00	Unit	0.26	1.04
¾” x 1/8” bolt	36.00	Unit	1.45	5.79
7/16” nut	6.00	Unit	0.02	0.12
½” nut	8.00	Unit	0.13	0.75
1/8” nut	72.00	Unit	0.26	1.04
Anti-slip tape	7.50	Meter	0.01	0.49
Flexible material	3.00	Meter	0.02	0.12
Epoxy paint	1.00	Liter	0.05	0.39
			Total	US$ 111.34

Figure 3 shows the side view of the sample collector assembled with its components. The chassis was constructed with U-shaped reinforced steel profiles. Each longitudinal bar (1) was 2.60 m long, 75 mm wide and 40 mm thick. The transverse bars (2) were made with the same material as the longitudinal bars, differing only in length, which was 0.95 m. The entire chassis has an approximate mass of 15 kg.

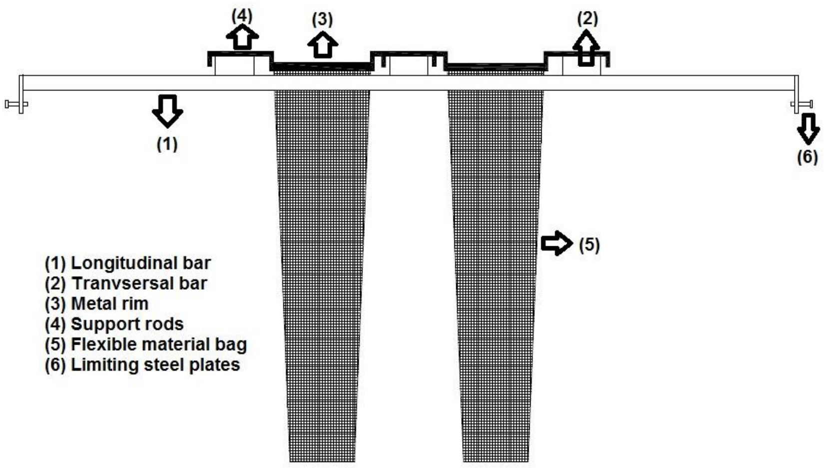

Figure 3. Side view with all components assembled forming the collector.

The longitudinal and transverse bars were joined by 7/16” x 2” hexagonal bolts with thick thread and fastening nuts with an internal diameter of 7/16”. To join the bars, the bolts were positioned at the end of the transverse bars.

Limiting steel plates (6) with dimensions of 4” x 3” x 5/16” were welded at the ends of each longitudinal bar and, on each plate, a nut with internal diameter of ½” was welded to guide the bolt (2” x 1/2” hex head bolt). To keep the bolts tightened, nuts with internal diameter of 1/2” were used to lock the bolt shank to the required extent. The use of anti-slip tapes on the profiles forming the chassis promoted greater operational safety for the operator to remove the sample collectors, and 7.5 m of anti-slip tapes were used on the chassis.

The sample collector consisted of a rim made from metal plates, a bag made of flexible netting and metal rods as a support.

The sample collector container rim (3) was constructed from a 1” x 3/16” 1020 steel plate (Figure 8). The rim was opened in its perimeter so that the flexible material bag was inserted. Its loose ends were later joined by means of two 3/4” x 1/8” slot head bolts and four nuts with internal diameter of 1/8”. The holes located in the body of the rim have the function of assisting in the union with the support rod.

A flexible netting (5) was chosen to be used in the sampling bags. Each bag has an approximate volume of 0.0471 m^3. This material does not prevent the interaction of the internal fruits of the collector with the external fruits. Another point observed was the non-retention of water expelled by the fruits that may have suffered some damage and ruptured their surface membrane. The height of the bag was determined by the height of the trailer that will carry the bulk cargo, which in this case was 1.70 m.

After fixing each flexible material bag, the support rods (4) were attached to the rim. Each rod was constructed from a 1” x 3/16” steel plate and fastened to the rim by two 3/4” x 1/8” slot head bolts and four nuts with internal diameter of 1/8”. The distance between the ends of the support rods was 0.535 m.

Subsequently, all metal parts of the device were painted with white Epoxy paint so that they were properly protected against the salts contained in the water released by some fruits and against the weather.

The complete sample collector built has capacity for six sample collections at any x, y, z position of the trailer. Manual removal of the sample collector from the chassis is performed by disengaging it and raising it vertically. The top view of the complete collector assembled is shown in Figure 4.

Performance of use

Later, through a prototype constructed from the detailed design, the collector was observed under field conditions (Figure 5). Field tests indicated adequacy and success in relation to the functions and requirements of established designs: filling of sampling bags, removal of samples, and chassis resistance to the weight of collectors and operators. There was no loss in the loading of the remaining cargo or stops during harvest for filling the collectors.

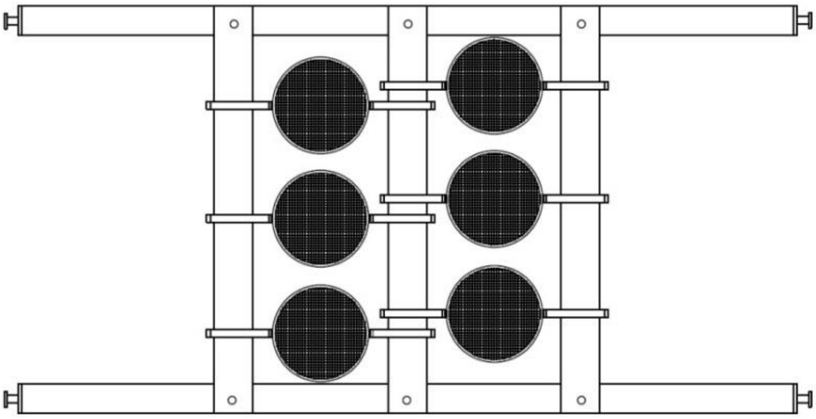

Figure 4. Top view of the complete sample collector.

Figure 5. Collector during harvest.

The developed fruit sample collector is recommended for sampling bulk cargoes, as its concept can adapt to the various types of transport reservoirs (trailers, wagons etc.). It can also have a variable number of collector containers. It is a portable system and, after sampling, the chassis is removed and the transport container enters the industry without any collector element.

The flexible material used to make the bag contained in the sampler assists in the interaction between the fruits that are inside and outside the collector. This interaction simulates, in an almost real way, the behavior of the cargo during transport, because the material is molded according to the forces working inside and outside the collector container. For being a netting, the material also does not retain water that is released by decayed fruits during transport, so only the solid parts of the fruits are collected.

Conclusion

The applied design methodology allowed the development of a sample collector for fruits transported in bulk cargoes.

The creation of the concepts of bulk cargo fruit collection mechanisms allowed the evaluation of some possible prototypes, which resulted in the choice of a single concept for the sample collector.

Field tests allowed verifying the effectiveness of the proposed concept, enabling the sampling of fruits during transport and at different positions along the cargo trailer.

The design developed resulted in the filing of the patent referring to the concept of fruit collection in bulk cargoes.

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