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Research paper

Development Prospects of Transportation in the Agroindustrial Complex by Reducing the Damage of Fruit and Vegetable Products When using the Pneumatic Container

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Abstract

The aim of the study is to reduce damage to potatoes in the body of vehicles when placed in containers for intrafarm transportation due to the development of new science-based technical solutions. Research methods are theoretical studies performed on the basis of laws and methods of theoretical mechanics. The task of the study is to determine the damage of potatoes when conducting laboratory tests on a shaker table that simulates the movement of a vehicle. The shaker table is a control unit, an installation that generates a reciprocating motion and a platform attached to the installation, which produces oscillatory movements of specified parameters. When imitating the movement of a vehicle, the following parameters were set: platform oscillation frequency from 6 Hz to 10 Hz, with increment of 2 Hz; the oscillation speed of the cargo platform from 1.8 m / s to 3.0 m / s, with 0.6 m / s increment and platform oscillation amplitude of 20 mm. Each stage of the experiment lasted for 2 minutes. According to the results of the experiment and the analysis of the damage to potatoes, the values of damage were obtained, which do not go beyond the maximum permissible agrotechnical requirements of 5 %, with the maximum specified vibration parameters. The results of the experiment suggest that the use of a pneumatic container leads to a decrease in the damage of potatoes when the vehicle is moving along a micro-profile of field roads. When using this pneumatic container, the share of damaged products decreases by 0.6-1.1 % with an increase in the vehicle speed by 1.7 times.

Keywords: *pneumatic container, transportation of fruits and vegetables, damage to fruits and vegetables, container transportation, container.*

1. Introduction

Agriculture occupies one of the key positions in the agro-industrial complex (AIC) of Russia. It accounts for over 48 % of the volume of products manufactured in the agro-industrial complex, 67 % of the labor resources involved in the agro-industrial complex and 68 % of the production fixed assets of the agro-industrial complex. In addition, in the USA, the share of production in the agricultural sector is 13 %, while the processing and marketing industries account for 73 %. The weak development of the processing industry in the agro-industrial complex leads to huge losses of agricultural products. Transport occupies not the last place in agricultural production. Modern agriculture is inextricably linked with technological vehicles used in cultivation, harvesting and transportation of fruits and vegetables [1, 2]. The development of agricultural production will result in the increase in transportation and freight turnover [3, 4]. When transporting agricultural products, you should also consider the loss of products that are associated with damage to the products being transported. The annual damage from losses during transportation amounts to 8 billion rubles. At the same time, transport costs reach 30-40 % of the production cost [5, 6, 7]. One of the options to reduce transport costs is the use of specialized rolling stock. However, specialization results in the increase in cost, complexity of the design and the inability to use vehicles outside this specialization. At present, agricultural enterprises for the production of fruits and vegetables have a shortage of specialized rolling stock, and the available equipment is either technically old, or its operation is associated with increased material costs for maintenance and repair. The acquisition of modern rolling stock to transport products is limited by the high cost of technology and is practically not acceptable for most agricultural producers. Therefore, it is advisable to look for some ways to improve transportation technologies when using universal vehicles, which include automobile and tractor transport.

As noted earlier, during transportation there are significant losses of fruits and vegetables, the causes of which are mechanical damage, for example, cracks, violation of the integrity of the shell, pressure and punctures, less often internal disturbances in the form of tissue softening and crushing occur. Mechanical damage leads to the loss of the appearance, reduces the grade of products and leads to its deterioration during storage. These circumstances significantly reduce the cost of manufactured products and, as a result, reduce the economic effect of its selling to the end-consumer [8].

Mechanical damage to fruits and vegetables occur when the vehicle body vibrates. Vibrations arise both for internal and external reasons and can reach values up to 3.5 g (g is the acceleration of gravity). Internal causes include the imbalance of parts and the unevenness of their rotation. Such reasons lead to high-frequency vibrations. Outside causes include irregular speed and uneven road surface. External causes are divided into single and permanent. A vivid example of single ones is vibrations that occur during acceleration, pivoting motion or slowdowning of the vehicle, when it gets into deep hollow spots. Constant or continuously operating vibrations caused by movement on an uneven surface of the roadway, especially relevant when driving on roads without asphalt pavement in field conditions. The main sources of vibrations are irregularities, non-constant hardness and moisture of the roadway [9, 10, 11]. Vibrations caused by external reasons have a rather large amplitude.

The very process of the appearance of mechanical damage is caused by a number of negative factors, such as the effect of solid sides of the vehicle on fruits and vegetables, and the effect of vegetables or fruits on each other. The latter is explained by the high amplitude of vibration of the vehicle body, resulting in a jump of the upper product layers and a collision when falling on the lower ones, as well as a significant increase in pressure from layer to layer, reaching maximum values on the lower layer. Accordingly, the greater the amplitude and the greater the number of layers of fruits and vegetables, the more negative the impact is. A large number of layers of fruits and vegetables is typical when transporting products in bulk.

The container way of transporting fruits and vegetables is often used in agriculture. This method does not only reduce the risk of losing fruits and vegetables, caused by a large number of layers as in the bulk method, but also solves the problem of optimizing the warehouse space during storage. When using the container method of transportation of fruits and vegetables, the time for loading and unloading is reduced, and the ability to install containers on tiers in tiers increases the useful volume of storage space.

Now a wooden container is widely used to transport fruits and vegetables. The size of the container varies depending on the product: 1200x1200x1600 mm for cabbage and potatoes; 1200x1200x700 mm or 1200x1000x700 mm for apples; 1200x800x700 mm or 800x700x500 mm - for others. The analogue of this container in Europe is the plastic container of the company “Wopla Plastiks” (Belgium). The dimensions of the container are 1100x1100x760 mm. The internal wall height is 650 mm. Similar in design parameters containers are made in Italy. They are 1200x1200x720 mm with the weight from 43 kg to 65 kg (manufacturing material is metal, plywood, fiber boards and wood). In the US, containers to transport products are made of plywood.

It should be noted that the use of containers does not completely eliminate mechanical damages. As a rule, the walls of containers are made of wood or other solid materials and, therefore, it is almost impossible to avoid the appearance of damage to products during transportation due to vibrations of the vehicle body.

Thus, creating new science-based constructions of vehicles for intrafarm transportation, aimed at reducing mechanical damage to fruits and vegetables in the agro-industrial complex of Russia, is a relevant scientific and technical task, the solution of which makes a significant contribution to increasing the productivity and efficiency of the agricultural sector.

The purpose of the study is to reduce damage to potatoes in the body of vehicles when placed in containers for intrafarm transportation due to the development of new science-based technical solutions.

2. Materials and methods

There is a growing variety of technologies for the production of agricultural products. The number of machinery and equipment types used in them also increases. The are created on the basis of modern materials and a wide range of components, caused by further expansion and deepening of investigations on the properties of crops, their fruit, peculiarities of growing conditions and the expansion of farm machinery use [12, 13, 14, 15].

The most difficult issue in preserving the quality of easily damaged agricultural products is damage that spoils their appearance, lowers the grade and increases the risk of spoilage. Spoiled products increase overall environmental tension, since such products need to be disposed of, and they can also cause poisoning when consumed, which in turn increases the cost of medical care and, consequently, increases the burden on the economy as a whole. Thus, damage and subsequent deterioration of easily damaged agricultural products are critical for both the ecological and food security of any state [16, 17, 18].

Transportation conditions have a particular impact on product quality [19]. To ensure the safety of the crop during transportation by truck and tractor rolling stock, a number of features of fruits and vegetables should be taken into account: seasonality of production and harvesting; uneven ripening; short deadlines for transporting products from fields and plantations after the harvest time; the use of different delivery schemes depending on the destination of the product [20].

The increase in the shelf life of products is significantly affected by the promptness in their transportation from the harvested areas of fields. This circumstance is due to the fact that, the environmental conditions during harvesting are often extremely unfavorable for its further transportation and storage. An actual problem in the organization of the harvesting process is also high-quality preparation of cargo for transportation. An example is the positive experience of transporting fruits and vegetables in California (USA), which showed that pre-sorting of fruits and vegetables in the field to eliminate rotten products can significantly improve the quality of delivery [21, 22, 23].

In order to reduce product damage during transportation from the field to the storage facility, the authors proposed a pneumatic container design, the walls of which are made of soft polymer material and have cavities filled with air, and the bottom is covered with soft damping material (Fig. 1).

Fig. 1: Appearance of pneumatic container

This pneumatic container is designed to transport uncalibrated fruits and vegetables. Overall dimensions of the pneumatic container are 1200x800x900 mm, which corresponds to the European standard of the pallet 1200x800 mm. Such overall dimensions allow optimizing the handling operations at warehouses using mechanized facilities, which, in turn, significantly reduces the time spent on warehouse logistics.

The device of the container is shown in Figure 2. The pneumatic container consists of a frame 3, onto which sections 1 are installed. They consist of separate, filled with air chambers 2, interconnected and forming the walls of the pneumatic container. The pressure inside the chambers is regulated depending on the type of crop being transported with the help of the pneumatic container.

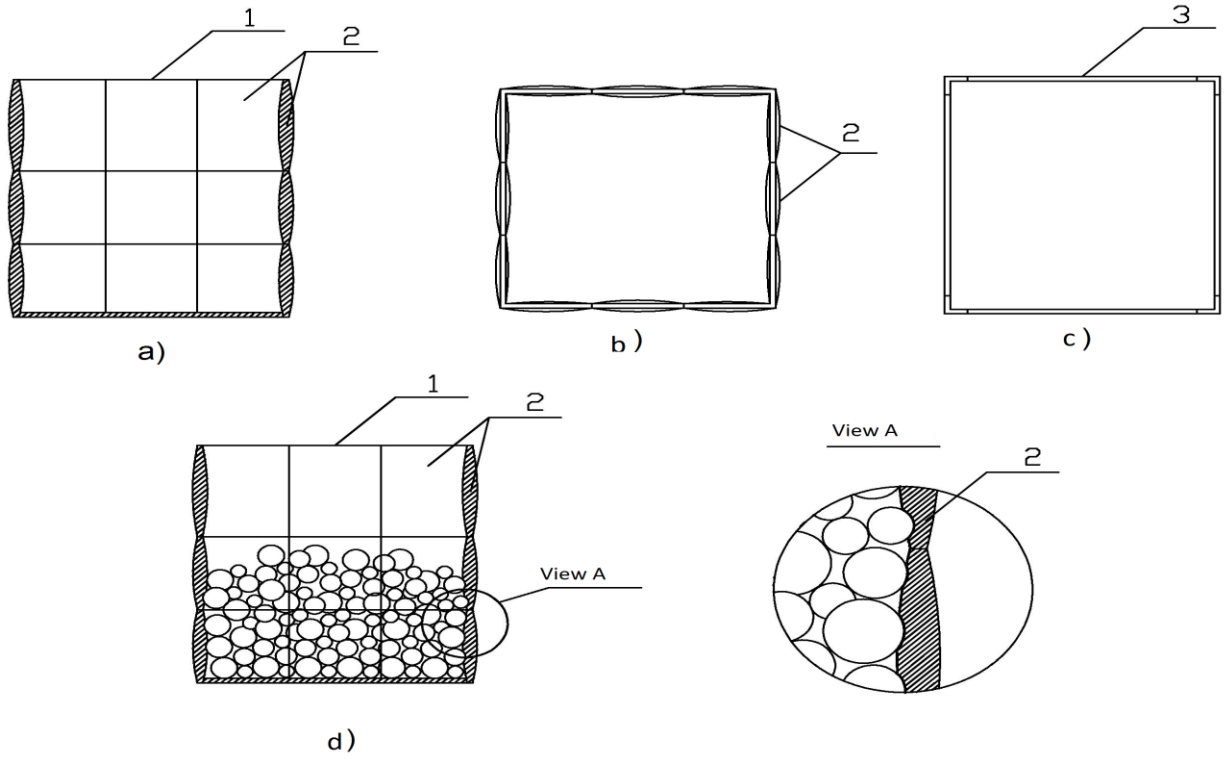

Figure 2: Design of pneumatic container

a – profile view; b – top view; c – frame of pneumatic container; d – pneumatic container filled with fruits and vegetables, profile view

The use of pneumatic container will reduce the amount of mechanical damage, and, consequently, reduce the damage to fruits and vegetables during transportation.

To confirm the theory of reducing the damage to fruits and vegetables using a pneumatic container, experimental studies took place at JSC "Corporation Phazotron-NIIR" with the help of shaker table VSB-250-445 (Fig. 3) that simulates vibrations of the vehicle body vibrations when traveling [24].

Figure 3 – Experiments with a pneumatic container at shaker table VCB-250-445

As a rule, experimental studies to analyze the damageability of fruits and vegetables are carried out naturally. When testing a theory based on the application of any invention or the proposed process, tests are carried out in the field. In this case a vehicle moving along the planned route is used. Then the damageability of fruits and vegetables is evaluated. In the course of such an experiment, a number of parameters is controlled, such as the speed of the vehicle, the volume or mass of fruits and vegetables, etc. At the same time, a number of parameters are not possible to control, although their impact is the key one. These parameters include vibration frequency, vibration speed, vibration acceleration, and amplitude (displacement). Data on these parameters are got from the measuring devices installed on the vehicle, then maximum and minimum values are determined and the average one is calculated. When using the previously mentioned shaker table, these parameters can be monitored and it is possible to get a real picture of the dependence between their changes and damageability of fruits and vegetables. The tests were exemplified by potatoes.

The maximum rates of acceleration and the frequency of vertical vibrations of the car body, where mechanical damage is likely to occur, are determined in the studies [19]. They are as it follows: the vibration frequency is 8 Hz and the speed of vibrations movement is 2.4 m / s.

In the experiment, the pneumatic container was installed and rigidly mounted on VSB-250-445 shaker table (Fig. 3). With the help of this shaker table, a vehicle movement was simulated with some specified parameters: the vibration frequency of the platform of the shaker table was in the range from 6 Hz to 10 Hz, in increments of 2 Hz; the speed of the vertical vibration of the platform was in the range from 1.8 m / s to 3.0 m / s, in increments of 0.6 m / s and the vibration amplitude of the platform of the shaker table was equal to 20 mm. Some variations of these parameters were made and after each of them a sample of potatoes was taken for analysis of damage [24]. Before the start of each variation, an unaffected potato was put into the pneumatic

container. The duration of each variation cycle was 120 seconds. Data on the duration of the cycle, were taken from an academic paper of Pustovalov V.S. [25]. The duration of the test (cycle), based on his research, is sufficient for 30 seconds. The duration of the cycle was increased for the reliability of the results.
For a comparative analysis of damage, a similar test cycle with the same parameters was carried out when installing plywood walls and bottom in the pneumatic container in order to simulate the effects of solid walls and the bottom of a wooden container on potatoes.

3. Results

After investigations at the shaker table and analyzing the damage to potatoes in accordance with the method, the obtained results are shown in Table 1.

Table 1: The results of potato damage evaluation when using pneumatic container

Vibration frequency of the shaker table platform, Hz	The speed of the shaker table platform, m / s		
	1.8	2.4	3.0
Damage to samples taken from a soft-wall pneumatic container, %			
6	2.9	3.7	4.4
8	3.4	4.2	4.7
10	4.1	4.5	4.9
Damage to samples taken from a pneumatic container with fixed solid plywood walls, %			
6	3.9	4.8	5.5
8	4.5	5.1	5.6
10	4.7	5.3	5.9

The allowable percentage of potato damage is 5 %. As can be seen from Table 1, when using a pneumatic container, the permissible damage limit is not exceeded and the result obtained during testing significantly improves the performance previously obtained by leading scientists in this field. When analyzing the data obtained, we see that the use of the pneumatic container having soft walls and the bottom allows reducing the damage of potato tubers by 15-20 % as compared to the pneumatic container having solid walls and the bottom made of plywood. The data on the limit values, which were taken as a basis, were obtained in investigations using either the vehicle body or the container used to transport products at the present time. The investigation results obtained when using the pneumatic container with installed walls and the bottom made of plywood confirm the limiting values obtained earlier. This indicates a significant advantage of the experimental pneumatic container over the containers currently used.

4. Discussion

Returning to the problems outlined above, there is a need to improve transportation, when using universal vehicles nowadays. The use of containers largely satisfies this requirement, as with the use of various types of containers the rolling stock does not need to be changed, and it is possible to transport containers even on a dump truck. At the same time, having assessed the supply at the market of containers, offered not only in Russia, but also in a number of foreign countries, we see that all presented containers do not exclude or even reduce the possibility of the impact of solid walls and bottom on fruits and vegetables, thereby not reducing damageability during transportation. The pneumatic container, in turn, solves the problem described above. Taking into account the fact that the proposed pneumatic container has no analogues, there are high chances that the design under consideration may be a new direction for the development of containers for agricultural transport, where the product itself, which requires transportation, that is, fruits and vegetables, often has a high probability of damage and, as a consequence, a decrease in grade and spoilage.
The possibility to adjust the pressure in the walls of the pneumatic container allows us to speak about its versatility for the transportation of crop products. The proposed design is suitable for various types of crops, while maintaining its effectiveness to reduce the damage. The use of this pneumatic container at the enterprise will reduce the possibility of damage during transportation of all fruits and vegetables. The versatility of the design eliminates the need to purchase a large number of different types of containers, which significantly reduces the cost of storing them during the off-season period.
It should also be noted there is a possibility of increasing the speed of vehicles during transportation without increasing the proportion of damaged products. Imagining the process of a vehicle moving with a load in the body, we understand that the driver primarily aims to bring the contents of the body to the place as quickly as possible, especially considering the seasonality of the harvest, because every day is important in the fall. And based on the data obtained during the experiment, it can be concluded that when using a pneumatic container, the threshold of maximum permissible damage is not exceeded at significantly higher platform speeds, that is, the vehicle body speed and, as a result, the threshold of permissible damage happens at significantly higher vehicle speeds [26].
Experimental studies were conducted on the example of potatoes not by chance. The process of transporting potatoes is one of the least studied processes, but no less demanding attention.
Let us consider the possibility of applying and introducing a pneumatic container into the process of potato harvesting and storing. Having examined and analyzed the process of potato harvesting and storing, currently used in agriculture, we see the following. Potatoes are dug using combine harvesters or other specialized equipment. This technique is equipped with a conveyor belt, where potatoes move to the vehicle. To speed up the harvesting process, potatoes are taken out of the field on a dump truck, less often on a dropside one. When delivered to the storage site, the potatoes are transferred into containers described earlier. This overload makes possible the rational use of storage facilities. Overloading is carried out, as a rule, with the help of some sorting mechanisms. From these sorting machines, potatoes move on a conveyor belt into containers. Then the containers are moved to the potato storage [27].
The pneumatic container can be used at any stage of the technological process of potato harvesting. Certainly, the use of containers directly during transportation from the field is more promising, but even if introduced into the already established scheme at the storage stage, it will also bring some significant economic effect. According to technological requirements, potatoes must be stored in rooms with a humidity value above the average. This is necessary so that the potato tubers do not lose moisture and retain their presentation. Wooden containers used in such conditions, for several seasons lose their technical characteristics and are destroyed, which leads to an increase in product damage during storage. The use of polymer material and stainless steel frame to manufacture the pneumatic container allows to increase the service life by several times as compared with a wooden analogue.
Let's pay attention to increase of economic efficiency of agricultural production when using the pneumatic container. The application of the proposed design in real conditions will entail a decrease in the proportion of damaged products during transportation and storage, which will ensure an increase in marketable products and, as a consequence, an increase in the volumes of products sold without attracting additional capacity. At the same time, as it has been mentioned above, the containers can be operated for a much longer period and, accordingly, less material resources will have to be spent on the purchase of new containers, which will lead to a decrease in operating costs. In addition, the cost of production will decrease, as an increase in the

volume of production causes some decrease of the costs of its harvesting, transportation and storage.
The use of the proposed pneumatic container also allows you to talk about the environmental component of its use. As it was noted earlier, damage and subsequent spoilage of easily damaged products increase the overall environmental tension and lead to negative consequences. By reducing the damage to fruits and vegetables, the pneumatic container contributes to solving this global problem. The use of pneumatic container leads to a decrease in the damage to fruits and vegetables. Consequently, the amount of spoiled fruit and vegetable products becomes significantly less, and less products need to be disposed of, respectively. If we talk about negative consequences of using spoiled fruit and vegetable products, then first of all it should be noted that the fewer spoiled products we have, the fewer chances to use them exist. The fewer products, made of spoiled fruits and vegetables, are delivered for consumption by the population, the lower the risk of poisoning is. And the smaller the share of spoiled products is, the less temptation for dishonest producers to use it is, as the total percentage of losses will be reduced.
The pneumatic container is connected with one more global environmental problem. As it can be seen from the description of pneumatic containers used at the moment, wood is most widely used for manufacturing. At the same time the global environmental community is worried by deforestation. The proposed pneumatic container does not have any wood elements in its design. Accordingly, its widespread use will not only not worsen the current situation, but will allow, albeit to a small extent, reduce wood consumption and, consequently, reduce the volume of deforestation.
The search for new science-based technical solutions in all sectors of the agro-industrial complex has been conducted quite successfully, especially recently. All new technologies are being improved and applied. However, if you pay attention to the process of transportation of fruits and vegetables, you can see that the technologies and devices that are used have not been changed for a long time. The share of losses during transportation of fruits and vegetables is still high, and this indicates that there is something to strive for and to improve in this direction [28]. The attention of the scientific community is more focused on other areas and technologies, such as obtaining new varieties of crops, the process of harvesting and tillage, fruits and vegetables processing, and so on, but the transportation process takes place in each of these areas and the success of the whole complex may largely depend on it [29].
The prospects for the development of transportation in the agro-industrial complex are currently quite significant, as there is something to improve and achieve positive results. Since during transportation one of the main criteria is the loss of production, accordingly, the improvement of the transportation process should be aimed at reducing the damage to fruits and vegetables.

5. Conclusions

The experiment resulted in validating the theory of reducing the damage to fruits and vegetables when using a pneumatic container and, as a result, reducing the negative impact arising from the contact of solid sides and the bottom with fruits and vegetables due to the use of inflatable walls and some damping material on the bottom of the pneumatic container. The use of the pneumatic container when transporting fruits and vegetables is an advanced direction for container transportation in agriculture and in the agro-industrial complex as a whole, not only in Russia, but also in the world.
The use of pneumatic container can also open new horizons in the design and use of containers for transportation in agriculture. The lack of analogues, both at the market for this product and in scientific research indicates some underestimated potential of this type of containers.
In the course of a more comprehensive analysis of the obtained results, it can be stated that the pneumatic container allows increasing the speed of the rolling stock during transportation without loss and damage to fruits and vegetables, or, in other words, reducing the proportion of damaged products with the same intensity of transportation.
At the same time, the introduction of the pneumatic container into the existing schemes for the transportation and storage of fruits and vegetables will not require any changes. The design of the pneumatic container and its overall dimensions completely coincide with the containers used, but at the same time, they considerably exceed their analogues in other characteristics. The materials, the pneumatic container is made of, also allow to make a conclusion about the economic and environmental feasibility of its use.
All this allows stating with confidence that the improvement of container transportation by introducing and using pneumatic containers is one of the advanced directions for the development of transportation in the agro-industrial complex and reducing the damage to fruits and vegetables.
The use of pneumatic containers makes it possible to solve not only the set goals and objectives, but also to contribute to a number of other, larger problems, both at the level of our state and at the global level.
Improving the efficiency of the agro-industrial complex of the country, by reducing the cost of producing fruit and vegetables and increasing the volume of the product itself, when using the pneumatic container, will lead to some improvement in the economic situation of the state, which is a question of present interest. Improving the efficiency of the agro-industrial sector of the country will lead to the improvement of the economy and reduce its dependence on external factors.
Speaking about the global problems affected by the pneumatic container, we can note its indirect influence on the ecological situation. Environmental problems are not problems of a single state, but of the entire world community. If a problem of this type arises in a separate state, the rest of the countries have to solve it in the future.
The large-scale use of pneumatic containers can have some positive trends in such issues considered in the ecological state of the planet as deforestation, utilization of spoiled fruit and vegetable products and poisoning when using spoiled fruit and vegetables.
The indirect influence of mass use of pneumatic containers on deforestation is due to the fact that wood is not used in its design.
The need for utilization of spoiled fruit and vegetable products will be significantly lower, since the use of pneumatic containers reduces the damage and, as a result, there will be less spoiled product. This is what will affect the reduction of the possibility of poisoning when using spoiled fruit and vegetables. The fewer spoiled products exist, the lower the risk of poisoning is, as well as the lower risk of its use by unscrupulous manufacturers is.
At present, the authors are conducting some patent research aimed at implementing the idea of creating this type of container, which will allow us to assert the due scientific novelty of the proposed design of the pneumatic container.

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