AN APPARATUS TO STUDY COMPRESSION STRESS IN FRUITS AND VEGETABLES[1]

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ABSTRACT - An adjustable and continuous multiple force applicator was developed, to study compression stress related to the transporte and storage of fruits and vegetables, using a cylinder-embolus system of a 10 ml syringe, a two-stage pressure controlling valve, air distributor device and a compressed air tank. The equipment is a modular one with 12 force applicator units (regularly spaced of 8.5 cm) connected to the pressure regulator through the air distributor. To apply the compression force, a 3,35 cm (od) acrylic ring was glued to the embolus. The test of the equipment showed an excellent correlation (R^2 = .9996) between the adjusted pressure and the applied force. During a real case study, mature-green 'Kada' tomato fruits were stored at a temperature of 20 ± 3°C under forces of 0, 2.25, 4.50 and 9.21 N that caused increasing levels of deformation, delayed the color development and reduced the CO_2 evolution as a function of the compression force, differently from what happens in the case of impact and vibration stresses.

Index terms: ecophysiology, equipment, *Lycopersicon esculentum*, mechanical injury, packing, postharvest, tomato.

UM EQUIPAMENTO PARA ESTUDAR ESTRESSE DE COMPRESSÃO EM FRUTAS E HORTALIÇAS

RESUMO - Para estudar o estresse de compressão em seus aspectos teóricos e aplicados durante o transporte e armazenamento de frutas e hortaliças, desenvolveu-se um equipamento para a aplicação de força de compressão ajustável e contínua. Consta basicamente de cilindro e êmbolo, de uma válvula de ajuste de pressão de dois estágios, e de um tanque de ar comprimido. O equipamento consistiu de nódulos com uma válvula de ajuste de pressão, conectada a doze unidades aplicadoras de força, regularmente distantes 8,5 cm umas das outras. Para a aplicação da força de compressão, colou-se em cada êmbolo um círculo de acrílico de 3,35 cm (diâmetro externo). Em testes experimentais obteve-se excelente correlação entre a pressão ajustada e a força de compressão (R^2=.9996). Durante o estudo de um caso real, frutos verde-maduros de tomate 'Kada' submetidos a forças de 0, 2,25, 4,50 e 9,21 de N durante duas semanas de armazenamento na temperatura de 20 ± 3°C, apresentaram níveis crescentes de deformação, atraso no desenvolvimento de cor e redução na taxa de evolução de CO_2, ao contrário do que ocorre nos casos de injúria de impacto e vibração.

Termos para indexação: ecofisiologia, equipamento, dano mecânico, *Lycopersicon esculentum*, pós-colheita, tomate.

INTRODUCTION

The susceptibility of fruits and vegetables to compression stress depends on the nature of the product, applied force and the time of exposure, skin resistance and absorbed energy (Mohsenin et al. 1962). Factors such as cultivar and

[1] Accepted for publication on October 3, 1991

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topology of the stressing force are also important (Dedolph & Austin 1962). Some products are more susceptible to compression than to impact of vibration. Holt & Shoorl (1982), for example, indicates that strawberry is extremely susceptible to compression injury. Similarly, tomato and khaki are also susceptible to compression injury and large losses occur when they are packed in tall boxes, with several layers of fruits. In some case, however, the use of pads to provide some compression force to the surface layers of the product in a box can reduce the rolling or vibration damage during the transportation (Olorunda & Tung 1985).

The purpose of this work was to design and build an equipment to study the stress of compression in fruits and vegetables. One compression stress study with 'Kada' tomato fruits was performed, and some uses for applied and basic research are discussed.

MATERIALS AND METHODS

The equipment was developed to apply static forces to fruits and vegetables, simulating their transport and storage environments consisted of a compressed air tank, a two-stage pressure controlling valve and a system of cylinder and piston (Fig. 1). The equipment has twelve force applicators (Fig. 2) constructed with glass cylinders and embolus from 10 ml glass syringes mounted on a wooden support at regular intervals of 8.5 cm. The lateral spacers between the two wooden supports and wooden base is interchangeable and can have different heights according to experimental needs.

Figure 1 is a diagram of one of the module units applying force to fruit. The glass cylinder is fixed using a ring of acrylic ring over a leveling rubber ring with two screws. At the base of the embolus a 3.35 (od) disc of acrylic was glued to uniformly apply the compression force to the organ under study. Each syringe in the system was connected to an outlet of the controlled pressure distributor (Figs. 1 and 2), using plastic tubes of 0,5 cm (od) with a length of 1,5 m. The connections between the plastic tube and the syringes were made using a number 12 needle according to the detail shown in Fig. 1. This kind of connection is convenient for experimental purposes since it allows randomization of forces when several modules are being used on a single experiment.

Figure 2 shows a set using a mercury manometer that is very accurate and suitable to study delicate fruits like tomatoes. For more robust structures, suitable Bourdon type manometers can be used.

The use of this force application system does not preclude the measurement of gas exchange. To measure CO_2 and etilene evolution, for example, the force can be applied over the commodity chamber closed with a thin film of PVC, while a known flow of air pass through the chamber (Calbo, 1989).

For its operation the product is placed under the embolus, with or without the commodity chamber to study gas exchange, with the low pressure manometer at zero, the needle valve connecting the pressure regulator to the distributor is opened; after, that the desired pressure is adjusted by turning the two stage valve knob in the clockwise direction.

Performance

The equipment behavior was evaluated in four experiments:

1. Time course of the force applied by one applicator as measured by an electronic balance having precision of 0.001 g, when the pressure was adjusted to 0,0555 MPa.

2. Evaluation of the coefficient of variation from balance measurements of the applied force for each of the force applicator units.

3. Regression analysis for the relationship between adjusted pressure and measured forces and for estimated force against measured force.

4. Finally, using three of the modules a real case study was carried out with mature-green 'Kada' tomato fruits harvested from Centro Nacional de Pesquisa de Hortaliças experiment field. Fruit samples were subjected to four force levels, 0, 2,25; 4,50 and 9,21 N, during two weeks at 20 $\pm$ 3°C. These levels, according to preliminary measurements, can occur inside wooden boxes typically used for transport of tomatoes in Brazil. The experiments had a completely randomized design with twelve replicates of one fruit. The compression stress effect on the color development was evaluated according to USDA standards (1985). Respiration estimates were obtained from CO_2 measurements, with a CG-3232 gas-chromatography equipped with a 1/8' x 2 m poropack N column and a thermal conductivity detector, in 1 ml air samples taken from the stressed fruits in a flow-through system (Calbo 1989). The fruit longitudinal deformation was also evaluated.

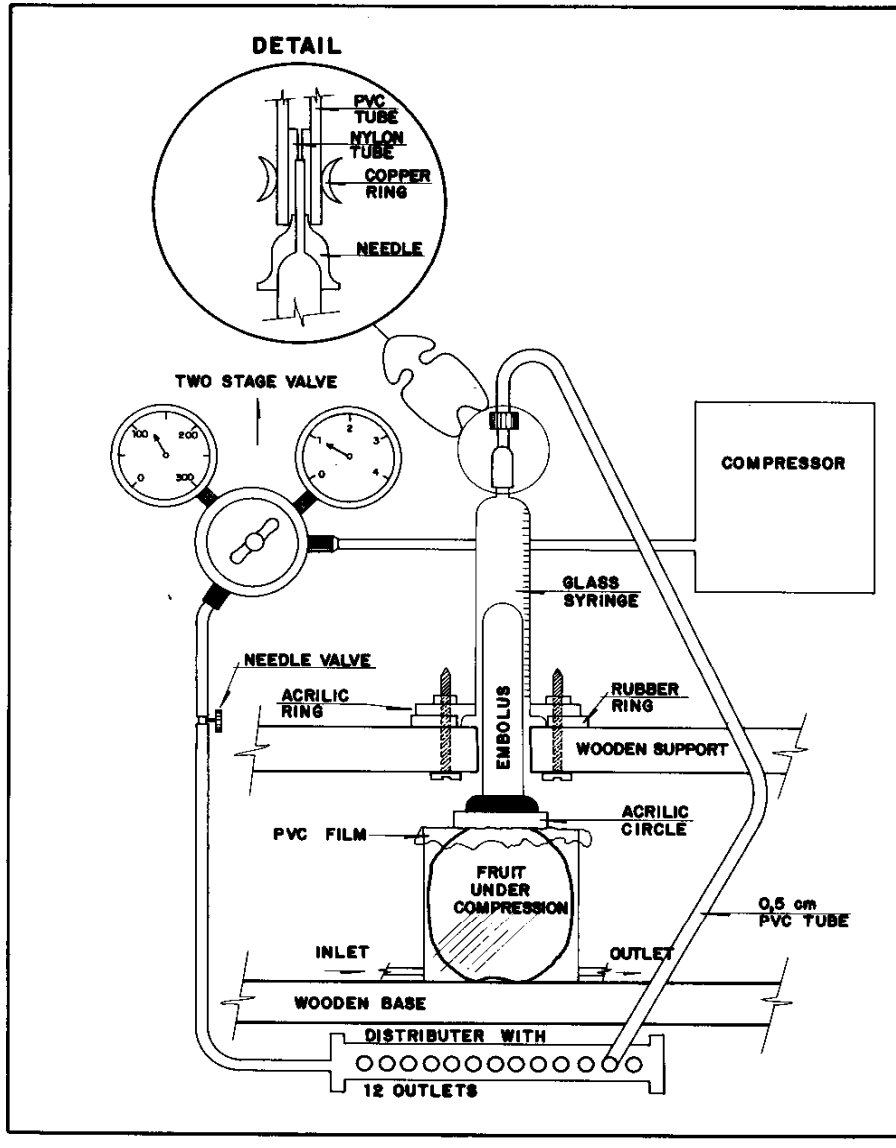

FIG. 1. Basic details of the equipment used to apply compression stress.

RESULTS AND DISCUSSION

In order to evaluate the performance of the equipment, some measurements relating adjusted pressure, to time and to the variation of the applied force were made. Fig. 3 presents a typical curve with excellent adjustment linearity between the pressure adjusted with the two stage pressure controlling valve and the compression force applied by an embolus. For

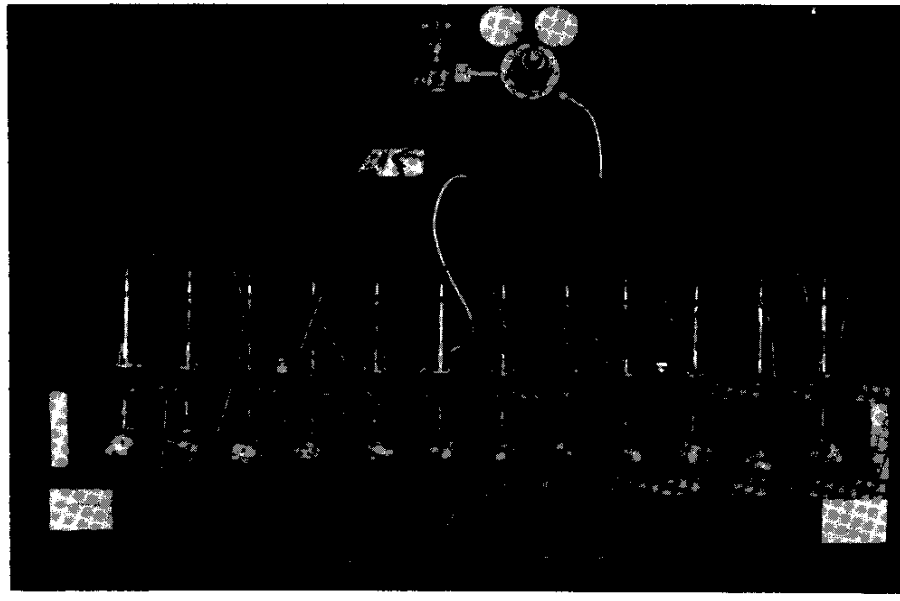

FIG. 2. Showing one module with 12 force applicator units, to study compression stress in fruits and vegetables.

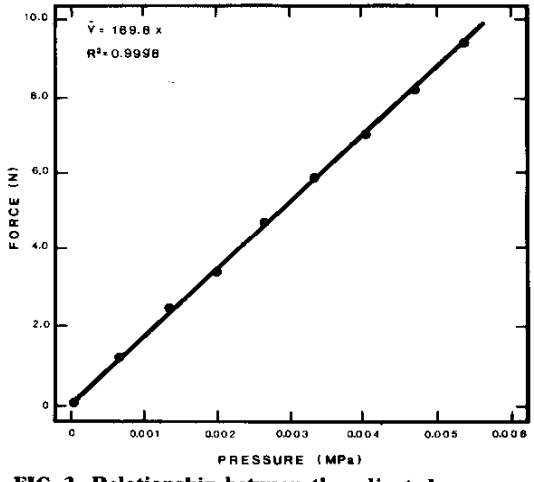

FIG. 3. Relationship between the adjusted pressure and the force applied by one force applicator unit.

the same data, the correlation between the observed force and the one calculated using the universal relation among force, pressure and surface area, was 0,99. The mean and standard error for the twelve elements of one set using a pressure of 0,0555 MPa, was 5,064 ± 0,074 N, while the mean and standard error for the embolus was 1,537 ± 0,008 cm. Fig. 4 shows the observed relationship between the adjusted pressure and time. An initial pressure reduction

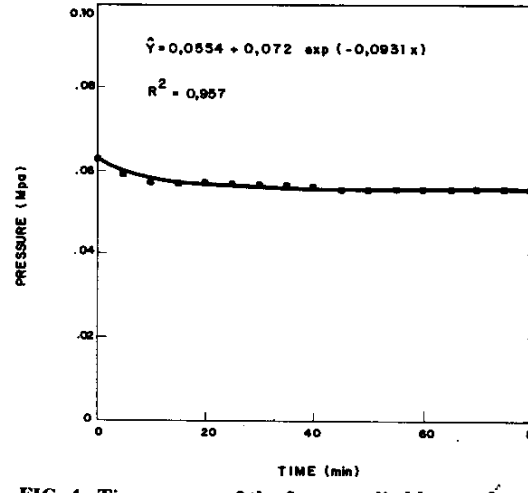

FIG. 4. Time course of the force applied by one force applicator unit operating at 0,0553 MPa.

before the curve leveling off was observed after the placement of the pressurized embolus over the balance.

For the compression stress study example with 'Kada' tomato fruits, Fig. 5 shows that the color development of the tomato fruits was delayed as a function of the applied compression stress. Differently from previous results, where tomato fruits were subjected to impact

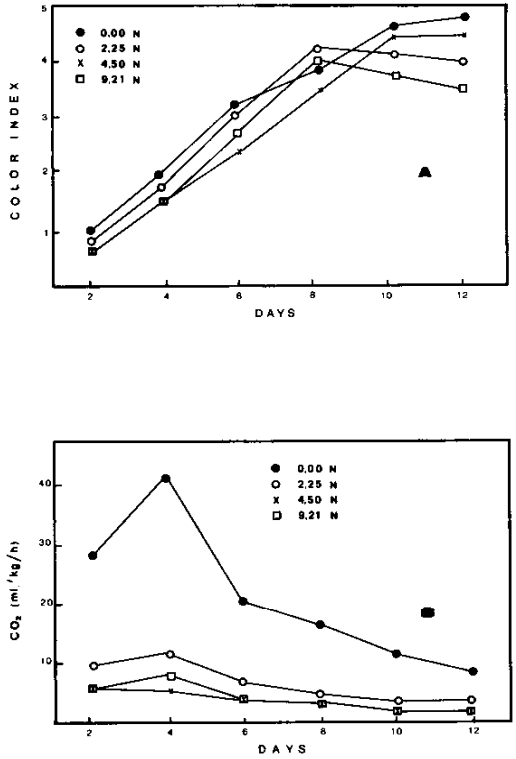

FIG. 5. Color development (A) and CO_2 evolution (B) of mature green tomato fruits stored at 20 ± 3°C under 0; 2,25; 4,50 and 9,21 N of compression stress. Color index criteria: 0- mature green fruit, 1- up to 10% of the surface covered with a yellow tannin color, 2- 10 to 20% of the surface covered with yellow tannin or pink, 3 - 20 to 60% of the surface tannin to red, 4- 60 to 90% of the surface covered with red and 5- fruits with more than 90% of its surface covered with red color.

(Kader 1987) or vibration (Ishii et al. 1990), the respiration decreased with the applied compression force. As it could be expected, the fruit deformation increased with increase of the applied force.

The results show that the equipment is good to study compression stresses applied to fruits. The adjustment of the applied forces is easy and can be confirmed by an electronic balance. The equipment is stable in time, allows the use of randomization and gas exchange measurements using the flow-through system. This equipment can be used in applied studies of compression stresses, that are fundamental for transport and storage of fruits and vegetables, especially in relation to package sizing. From an ecophysiological view point, the compression causes the formation of contact areas among the packed organs, that eventually causes small wound in the presence of impurities such as sand grains, or vibration. Those contact areas are possibly the most suitable points for the development of infections, because in there the water potential is very similar to the plant water potential, instead of the storage relative humidity. This ecophysiological approach, apparently forgotten, can also be pursued using this force applicator system.

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