VEGETABLE CROPS DEFORMATION ASSAYS FOR PACKAGE HEIGHT DEFINITION: A NEW APPROACH

Ensaios de deformação mecânica de hortaliças para a definição da altura de embalagens: Um novo enfoque

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ABSTRACT

In the present work one determined the threshold pile height below which cracking and other deformations do not occur in products with low apparent density such as lettuce, collard greens and bell pepper. Initially the threshold pile height was sought applying decreasing compression stresses equivalent to pile loads of 160, 120 and 80 cm, with four replicates in four hour assays. The safe threshold pile height which protects the products against cracking rupture in these three commodities were of 80 cm. In a complementary study, plastic and elastic deformations induced by this safe pile threshold height were measured. The irreversible deformation, plastic deformation component, were lower in bell pepper (3.8 %), medium in lettuce (4.23 %) and had the higher values in collard greens (10.2 %). The reversible deformations, the elastic component, was also the lower in bell pepper (4.14 %), medium in lettuce (7.41 %) and the higher in collard greens (8.17 %). Considering these modest plastic deformations, the safe pile threshold heights were accepted and the safe package heights were defined as the pile threshold height multiplied by a factor of 0.5. This safety factor incorporates protection against accelerations of impact and vibration which occur during handling and transportation, as it was previously used for the development of packages for compact fruits and vegetables with higher apparent density. According to the method used the maximum package height should be of 40 cm, for the low density model products of this study.

Index terms*:* *Brassica oleraceae acephala*, *Capsicum annuum*, *Lactuca sativa*, pile height, post-harvest.

RESUMO

Neste trabalho, determinou-se a altura limiar de pilha, altura abaixo da qual não ocorrem rachaduras e outras deformações que são prejudiciais em alface, couve e pimentão, três produtos de baixa densidade aparente. Primeiramente, determinou-se a altura da pilha abaixo da qual não ocorrem rachaduras. Para isso os tratamentos foram compressões decrescentes. Essas compressões decrescentes foram 160, 120 e 80 cm de pilha, aplicadas com 4 repetições, durante 4 horas. A altura limiar de pilha estática que protege contra rachaduras nesses três produtos foi 80 cm. Em seguida, estudaram-se as deformações elásticas e plásticas causadas por essa altura de pilha limiar e observou-se que a parte irreversível da deformação, componente plástico, foi menor em pimentão (3,8 %), média em alface (4,23 %) e maior em couve (10,2 %). As deformações reversíveis ou elásticas também foram menores em pimentão (4,14 %), médias em alface (7,41 %) e maiores em couve (8,17 %). Tendo-se em vista as modestas deformações plásticas aceitou-se a altura limiar das pilhas e definiu-se a altura das embalagens como a altura limiar dividida por dois, para incorporar proteção contra acelerações de impacto e vibração durante o manuseio e o transporte, da mesma maneira anteriormente para frutas e hortaliças compactas e de maior densidade aparente. Desse modo para essas três hortaliças modelo, de baixa densidade aparente, igualmente a altura máxima definida para as embalagens foi de 40 cm.

Termos para indexação: Altura de pilha**,** *Brassica oleraceae acephala*, *Capsicum annuum*, *Lactuca sativa,* pós-colheita.

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INTRODUCTION

Mechanical injuries are irreversible plastic deformations which in some cases evolve to cellular ruptures in organ cracking and other cellular and tissue disruption effects. They are caused by external forces, resulting in mechanical damages or physiological, chemical, and biochemical changes of color, flavor and texture (CALBO et al., 1995; CASTRO et al., 2001; HOLT & SCHOORL, 1982; MOHSENIN, 1970). Inadequate packages can cause mechanical injuries in vegetable crops by inducing compression and acting as a cause of abrasions, cuttings, crackings and undue impact acceleration transferences (KAYS, 1991; WILLS et al., 1998).

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Considering IBGE (2004) information, leafy vegetable crops include the following species: watercress, lettuce, Swiss chard, chicory, broccoli, chives, coriander, collard greens, cauliflower, spinach, parsley, cabbage, celery, artichoke, leek, asparagus, sour, Indian spinach, mint, oregano, leaf mustard and roquette. Leafy vegetable crops according to Filgueira (2000), are herbaceous plants which are succulent, tender, grown above ground, commercialized in different supermarkets and used in human nutrition. Besides leafy vegetable crops itself, this group includes shafts and stem apices and stumps (asparagus, celery) and flowers (cauliflower, broccoli, artichoke). The most important leafy vegetable crops commercialized in Brazil, each one exceeding 9.000 tons per year (IBGE, 2004) are watercress, lettuce, Swiss chard, chicory, broccoli, chives, parsley, escarole, coriander, collard greens, cauliflower, spinach, parsley and cabbage. In this paper lettuce and collard greens were studied as representative models in this low apparent density vegetable crops universe, considering their preeminence within the leafy vegetable crops group.

Package and pile heights are parameters which practical value is modulated by commodity firmness characteristics and commercial practices. Firmness of plant organs, such as a fruit or a leaf, is influenced by many factors. The volume and cell number, tissue type and the intercellular volume influence the plant structure (MOHSENIN, 1986). The elasticity and rigidity of plant tissue are due to cell wall, whose properties are due to cellulose microfibers, hemicelluloses, pectins and lignins. Water content and cell turgidity are also important in tissue rigidity (FALK et al., 1958).

Methods to evaluate packages for fruits and vegetables are usually strongly dependent on package materials and mechanical resistance concerns, along with pure mechanical representation of plant organs with no bearing on the real plant physiology fundaments, as it was revised by Peleg (1985). Luengo et al. (2003) used flattening methodology to determine the commercialization package height for a range of compact globoid vegetables and fruits that included mangoes, potatoes, onions and tomatoes. Turgor dependent firmness methodology developed in that work, however, is not adequate for non-compact organs with low apparent density such as leafy vegetable crops and bell peppers, for which the turgor dependent firmness is not clearly related to the capacity to support compression and consequently does not allow valid inferences about the definition of pile heights. In most low apparent density commodities the spatial disposition of layered tissues are prone to deformations, which above certain intensities can result in cracks, such as those in the midrib tissues of leaves. Consequently, for bell pepper and leafy vegetable crops a different plant physiology based method is required to define the threshold pile and package height to protect these products from cracks and other excessive plastic organ deformations.

Among the leafy vegetable crops, lettuce and collard greens are of preeminent commercial importance. For collard greens, cultivar Manteiga is by far the most relevant. The amount of commercialized lettuce in Ceagesp, in 2003, was 13 tons, of which 6.4 tons are of the crisphead type (AGRIANUAL, 2004), the main lettuce group from which a cultivar was selected for this study. Magali bell pepper (*Capsicum annuum* L.) was used as a model in this study because it is the most commercialized group.

In this paper compression induced product pile threshold height below which cracking did not occur was used as methodological tool to define package height, whereas plastic and elastic deformations were used as auxiliary indicators to estimate pile and package height, which should confer practical protection to some of the listed mechanical injury factors during handling and transport of low density product. In other words the purpose of this work was to define threshold pile and package heights to protect low apparent density model of vegetable crops during handling and transportation. Lettuce, collard greens and bell pepper height stress tolerance was evaluated based on new assay methods to estimate threshold product pile height to assure the product is protected against compression cracking and excessive plastic deformation. For this study a transparent assay package and a plate to uniformly deliver the simulated height loads for reliable commodity deformation measurements were used.

MATERIAL AND METHODS

The concept of plastic and elastic deformation of Levitt (1980) was used for measurements as it follows: Elastic deformation was measured as a reversible and nearly time independent process. Plastic deformation, on the other hand, was a measure of the time dependent plant viscoelastic deformation, which magnitude increases up to an eventual rupture, as a function of the applied force and of the exposure time. Consequently, according to these notions the measurements were of two types, basically. In the first a determination of a safe threshold limit, below which the possibility of viscoelastic rupture, cracking, to occur is negligible and a second type of assays in which this safe threshold height stress was applied to evaluate the plastic and elastic commodity pile deformation response.

An assay package

To do these experiments a transparent glass box, 40 cm high, with base dimensions of 60 cm and 50 cm was used as an assay package. Additionally, in this package each product with apparent density was measured dividing the commodity packed weight by the internal assay package filled volume.

The accessories for the assay package were a 50 kg balance, a weight set, a digital sliding caliper and two flat plates measuring 59.5 cm by 49.5 cm one made of glass and other of polystyrene.

In the package assay, the weights, corresponded to 3, 2 and 1 times the test package filling weight in order to simulate pile heights of 160 cm, 120 cm and 80 cm. The weights were applied over the product with aid of the flat plates. The application of the zero weight was done placing the polystyrene plate, with negligible weight, horizontally over the commodity in the package.

The product pile deformation during such load simulation was followed with aid of a sliding caliper. Height was measured outside the transparent package in four median positions, in which the flat plate borders, faced the transparent box walls.

The occurrence of cracking was expressed as a percentage value for a given commodity as a function of the simulated pile height. Elastic deformation was estimated based on the recuperation of leafy vegetable height inside the package and the plastic deformation was estimated according to the residue between total height variation and the measured elastic recovery.

Plant material

Lettuce (*Lactuca sativa* L.) cultivar Verônica, a looseleaf cultivar of the 'Grand Rapids' group, collard greens (*Brassica oleraceae var. acephala*) leaf bunches from cultivar Manteiga, and bell pepper (*Capsicum annuum* L.) fruits cultivar Magali were chosen among many other vegetable crops with low apparent density, considering their economical importance and their botanical characteristics.

For each experiment one of these vegetable crops was harvested in the Vargem Bonita agricultural district near Brasília-DF, by the end of the afternoon, after 4:00 pm. For lettuce, about 150 heads without defects such as yellow leaves, mechanical damage and disease symptoms, were selected. For collard greens around 300 commercial bunches with 7 to 10 leaves were selected. For bell pepper fruits eight 25 kg-boxes with selected commercial size fruits were selected. For each experiment the product was stored at room temperature in the farm until next morning and then they were transported to the post harvest laboratory at Embrapa Vegetables in Brasília. This procedure had the purpose to simulate the commercial conditions used for the harvest and the transportation of these commodities.

Pile height assays

In a first assay to study the product pile allowable height the transparent assay package was initially filled up to the top (40 cm). Treatments were weight forces applied over the commodity top layer with aid of the flat plate which exposed the commodities to stresses equivalent to pile heights of 160, 120, and 80 cm. Occurrence of cracking was evaluated in four replicates. The largest pile height that did not cause any cracking to a given commodity was named the pile safe threshold height.

A second experiment was aimed at studying pile induced plastic and elastic deformations caused by the pile safe threshold height, obtained in the first assay, which value was 80 cm. To perform this second experiment a load correspondent to the weight of a 40 cm lettuce layer was added over the top layer of the commodity in the filled package for one hour and then removed. Measurement of the pile height deformation was taken with aid of a sliding caliper. This pile height measurement was also continued during one extra hour after the weight removal, period in which the strain recovery was recorded. Deformation results were expressed as percentage in relation to the 40 cm of the initially full assay package.

Each experiment had four replicates and the statistical analysis was descriptive, graphically represented with standard error of the mean. Experiments with collar greens and sweet pepper were performed as described for lettuce.

RESULTS AND DISCUSSION

This work was aimed to complement the work of Luengo et al. (2003) to provide a new oriented tool commodity to define pile and package height for the handling, transportation and the commercialization of fruits and vegetables. In this article the focus was a methodological approach to define pile and package height for model commodities with low apparent density such as leaf vegetables and bell pepper. This work is different from the previously referred one which was purely based on the turgor dependent firmness measured with the flattening method and the product apparent weight which was previously used to define pile height for compact globoid fruits and vegetables (LUENGO et al., 2003). The model products used in this investigation are lettuce with an apparent density in the package of 0,21, collard greens with an apparent density of 0,17, and bell peppers with an apparent density of 0,27. The are low apparent density commodities with irregular shape which, consequently, cannot be subjected to a simple mathematical treatment for the direct conversion of turgor dependent firmness values ($kgf.cm^{-2}$) and of apparent densities into threshold pile heights, as it was previously done for more compact globoid vegetables by Luengo et al. (2003). For this reason the plant physiology approach used in this article was quite diverse and was strongly based on the notions of plastic and elastic strains put forward by Levitt (1980).

Lettuce

In the experiment carried out with lettuce, it was observed that compressions equivalent to piles of 160 and 120 cm cracked lettuce leaves, whereas in piles of 80 cm no cracking was observed (Figure 1). Consequently 80 cm was the experimental pile threshold level below which the lettuce leaf head was not subjected to pile induced load weight cracking.

Considering logistic operations, 80 cm is an interesting pile height for supermarkets but it would be a high package from an ergonomic point of view. However, for safe handling a package should have half of the threshold static load supported by the commodity according to Luengo et al. (2003). This is because a tolerance margin is needed due to the impact and vibrations accelerations which can easily reach 2 g during handling and transportation (LUENGO et al., 1997; MORETTI et al., 2002).

It was observed that total deformation (plastic plus elastic) registered after 60 minutes was 11.6 % (Figure 1). Most of the deformation developed during the first five minutes. The elastic recuperation occurred after the test weight was removed and was 4.23 %, and by difference the lettuce plastic deformation residue was 7.41%. Most of the elastic recovery in lettuce leaves compression occurred within five minutes after the load removal.

Although there are not similar experiments related with this methodology in literature, it is reasonable to affirm that a 7.41 % plastic deformation without the occurrence of cracking is an allowable strain to be accepted in the benefit of efficient pile in package handling. Of course the measured plastic deformation value is an upper limit, considering that for package height definition the static allowable pile height is multiplied by 0.5, and consequently the defined package height is 40 cm.

A previous standard method for lettuce firmness evaluation is the manual compression test, in a note scale

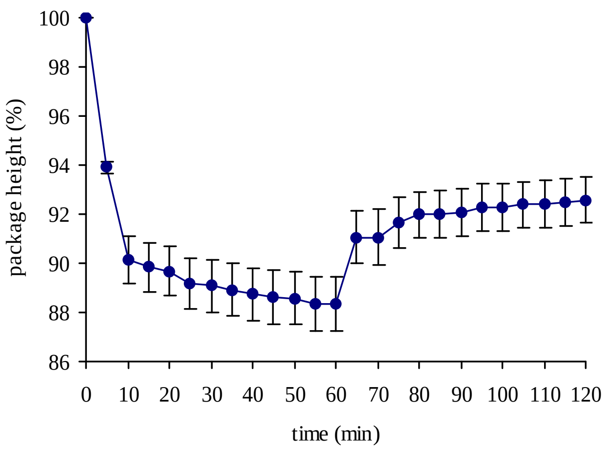

Figure 1 – Percent deformation of 'Verônica' lettuce pile in relation to the initial pile height (40 cm) inside the assay package, caused by an additional weight load used to simulate the effect of doubling the package height (40 cm). After 60 minutes the weight load was removed and the product recovery was followed in time. Observations represent the mean of four replicates and vertical bars represent the mean standard error.

from zero to five (KADER et al., 1973). This manual method is simple, but it needs training and is subjective. Schofield et al. (2000) developed an objective method to measure firmness in lettuces, which is not effective for crisp looseleaf cultivars. Traditional hand compression firmness scores of iceberg lettuce heads were compared with force-deformation data collected from parallel-plate compression tests conducted with a universal testing machine. Sample deformation was measured over a load range of 30 to 40 N. These methods, however, are useful mainly as important field harvest index tools. Consequently, the methods described in this work fulfill the need of a methodological tool to define allowable package heights for the industry, based on a plant physiology derived criteria.

Collard greens

In the experiment to investigate the pile height threshold below which leaf cracking rupture does not occur in collard greens, the results were similar to those ones obtained for lettuce. Simulated loads of piles of 160 and 120 cm provoked cracking, whereas a 80 cm height load caused no cracking in collard greens leaves, and, thus it was considered to be the experimental threshold height above which this commodity should not be statically piled up. Packages for post harvest, however, are not used only in static conditions, but they are also used for dynamic operations in handling and transportation. Considering this fact, and using the Luengo et al. (2003) procedure, a safety factor was defined. Consequently, as for lettuce, collard greens should be packed in 40 cm high packages. This assures that the elastic and plastic deformations suffered by the product during handling will be lower than the values herein reported for the 80 cm height deformation assay.

Plastic deformation estimates after one hour was 10.16%. In the same way as for lettuce, collard greens leaves compression occurred mainly in the first five minutes after the overweight removal. Total deformation (plastic plus elastic) was 19,33% after one hour with twice the load, and elastic deformation was 8.17% (Figure 2).

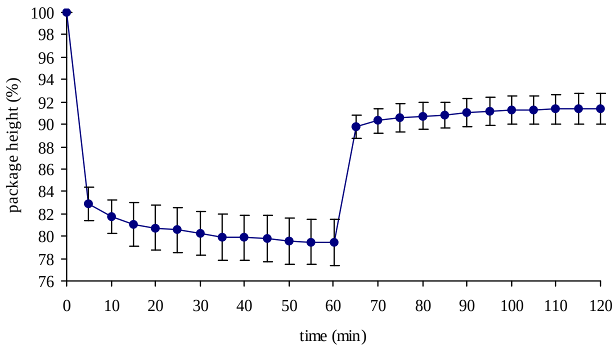

Figure 2 – Percent deformation of 'Manteiga' collard greens in relation to the initial pile height (40 cm) inside the assay package caused by an additional weight load used to simulate the effect of doubling the package height (40 cm). After 60 minutes the weight load was removed and the product recovery was followed in time. Points represent the mean of four replicates and bars represent the mean standard error.

Bell pepper

Bell pepper was included in this study due to its characteristic of low apparent density (0.06 kg l^{-1}), which make it as prone to cracks as turgid leafy vegetables.

In the experiment designed to estimate bell pepper threshold pile height bellow which no cracking occurs, it was observed that 160 and 120 cm loads caused fruit cracking, whereas piles equal or smaller than 80 cm did not cause bell pepper cracking. For this reason 80 cm was considered the threshold largest static load this fruit can safely withstand without suffering cracking rupture.

Plastic deformation after 60 minutes was 3.86 %, and it occurred mainly in first five minutes. After the 40 cm equivalent extra load removal, the recuperation in product height occurred mainly within the first five minutes. Total deformation was 8.00 % and elastic recovery was 4.14 % (Figure 3).

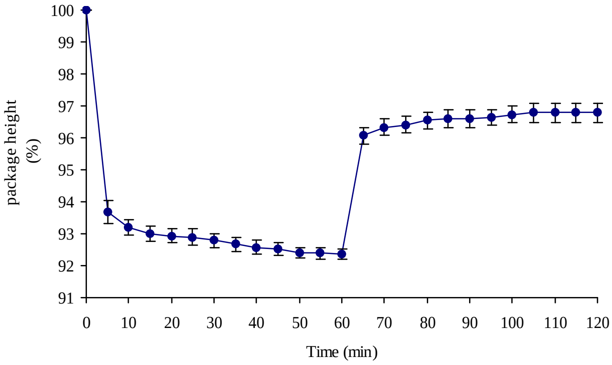

Figure 3 – Percent deformation of 'Magali' bell pepper in relation to the initial pile height (40 cm) inside the assay package, caused by an additional weight load used to simulate the effect of doubling the package height (40 cm). After 60 minutes the weight load was removed and the product recovery was followed in time. Points represent the mean of four replicates and bars represent the mean standard error.

This static height load was halved to attend dynamic handling and transportation using the criteria of Luengo et al. (2003), which included a safety factor as a protection against accelerations infringed to the products, by impacts and vibrations packages are exposed during loading, transportation, unloading and in several other stressing handling operations.

CONCLUSIONS

A simple transparent package method to estimate threshold pile height for low apparent density commodities such as lettuce, collard greens and bell pepper was developed. This method, besides enabling measurements of the threshold pile height, also enables measurements of product deformation measurements for the estimation of plastic and elastic recovery after weight, or pile load assays.

The experimental threshold pile height below which the commodities are not subjected to cracking rupture was considered equal to 80 cm in the three studied commodities, lettuce, collard greens and bell peppers.

Commodity plastic deformation is an irreversible function of time and applied compression load. Lettuce, collard greens and bell peppers subjected to the safe threshold pile height during one hour suffered only modest plastic deformation damage and presented elastic recovery of the same order.

According to the safe threshold pile height and a safety factor to consider accelerations the commodities suffer during handling and transportation the maximum package height for the investigated representative low density vegetables is 40 cm.

Maximum package height information along with in package apparent density, palletization and ergonometric considerations should allow the definition of packages to protect low apparent density vegetables against cracking rupture and excessive plastic deformation.

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