# IDENTIFICATION OF ADEQUATE PHYSICAL CHARACTERISTIC FOR IMPACT DAMAGE SUSCEPTIBILITY PREDICTION OF AN APPLE POPULATION

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**Abstract:** During the mechanical handling, the major causes of fresh fruit's pulp tissues damage are the impact of fruit with working surfaces and/or between themselves. Because of the natural variability of the fruit physical proprieties and the multiple factors involved in the process, recent studies shows that the impact damage susceptibility of an apple population can be statistically described by the damage probability, and the correlation between this and the impact level can be correctly expressed through a logistic function: $p = \dfrac{\exp(C+mX)}{1+\exp(C+mX)}$, in which $p$ is damage probability (decimal); $X$ – physical propriety characterizing the impact level; $C$, $m$ – logistic constants. In our testing, the impact level $X$ was characterized by: $E_{ci}$ – initial impact kinetic energy (J); $v_i$ – initial impact velocity (m/s); $a$ – maximum indent of the fruit during impact (mm).

With the data obtained in our experiments done on a 36 Jonathan apple population, subjected to controlled impacts using the pendulum method, was tested the logistic function. It was determined that the impact damage probability can be correctly described by the logistic type function and the most adequate physical propriety for the impact level can be considered $E_{ci}$. For $X = E_{ci}$, was found $C = -2.429$; $m = 9.939$ and a correlation coefficient $R^2 = 0.976$.

The relation is useful not only for prediction of the maximum threshold impact level $X$ for an admissible damage probability (5% or max. 10% in accordance with E.U. standards), but for the anticipation of the damage probability in case of a known value for the impact level $X$.

**Keywords:** impact level, apples, damage, susceptibility, probability, logistic function.

## 1. INTRODUCTION

During the fresh apple mechanical handling operations, after harvesting, for marketing or storage purposes, the fruits are subjected to mechanical stresses which cause tissue damages (bruises). It is considered that from the stresses to which the fruits are subjected, the most frequent and harming are the impacts (shocks) of fruit with working surfaces and/or between themselves. Impacts are the major cause of fruit's pulp tissues damage [1, 3, 9, 10, 12, 16, 19, 20]. These are emphasized by the changing colour in brown or by cracks in the pulp (with or without the cracking of epidermis). These damages are reducing not only from the marketing quality of the fresh fruit, but also from the storage time, causing losses [8, 10, 11, 16 – 19].

The fruit damage degree and the damaged fruit percentage in technical systems of handling, transport and sorting – packing, depends on fruit variety and its ripening degree, growth and development conditions in the orchard, design and functional values of the technical system, type and working regimen, time of operation execution (after or before a storage period) [2, 3, 8, 10, 11, 13, 14, 16 – 19]. On international scale the researchers have great concerns about impact behaviour evaluation of different varieties of fruits (especially apples) [1, 9 – 19] and also highlighting the research done in our country in this field [3 – 7, 20 – 24].

An important research direction is referring to the trials regarding the fruit impact behaviour study for the evaluation of damage degree and for developing mathematical methods which realize its correlation with the impact level, allowing the prediction of the impact damages [1, 3 – 6, 9, 12, 17 – 20, 22 – 24].

The published papers establish a great diversity of evaluation modes for the fruit pulp tissues damage due to impact, that is: 1) through the volume of damaged tissues [16 – 19]; 2) through the indent diameter of damaged tissue, visible on the fruit surface [3, 4, 11, 14, 15, 23]; 3) through the specific absorbed kinetic energy or the available specific kinetic energy to which the first bruised cells, invisible with the naked eye, appear (situated at 1.5 – 2.5 mm under the fruit epicarp) [3, 4, 12]; 4) through the impact damage susceptibility coefficient (defined by the available impact kinetic energy to which the first bruised tissues appear or the kinetic energy to which the fruit damage probability is not higher than 0.05 or maximum 0.10) [1, 22]; 5) through the damage degree appreciated by the probability that fruits do not contain over a specific number of points with damaged tissues or a specific surface with damaged tissues [2, 8].

In the last period there are developed methods for the prediction of the fruit's impact damage degree using the impact damage susceptibility coefficient with the impact kinetic energy value which does not exceed a certain accepted value of the damaged fruits probability [1, 2, 8, 22]. These paper objectives are: 1) identification of the suitable physical quantity for the characterisation of the impact level used in impact damage susceptibility evaluation; 2) establishing the correlation between the damage probability and each one of the considered physical quantity for the characterisation of the impact level; 3) evaluation (prediction) of the apples impact damage susceptibility index, Jonathan variety.

## 2. THEORETICAL CONSIDERATION

Due to the natural variability of the growth factors, fruits' physical proprieties and of the multitude parameters that intervenes in operations and influences the fresh fruits impact damage degree, after harvest, in technical systems of handling, transport and sorting – packing, it is preferable to develop a statistic relation for evaluation of the damage probability depending on a physical quantity which to characterise as good as possible the impact level and the fruits' physical proprieties [1, 2, 8, 22].

In accordance with data from [2, 8] is proposed that being satisfactory the damaged fruits distribution law as number of bruised points on its surface, in the sorted fruits number, described by the Poisson's distribution law:

$$p_m = \frac{a^m}{m!} \cdot e^{-a} \tag{1}$$

where: $p_m$ is the distribution (repetition) probability in sorted fruits number, of the fruits with a „*m*" bruised points number on the fruits surface (or the distribution law parameter; ex.: in case of apples' experiments, using machineries based on the weight sorting, $a$ = 1.8; and using sorting machineries with punched belt, $a$ = 1 [8]). In paper [2] it is presented an application using these values.

Using the relation (1) in practical situations it is uncomfortable and limited, needing anticipated experiments for each kind of machinery, working conditions and fruits categories (populations), for the determination of the distribution law parameter „*a*". With more promising results in practical use is the logistic law with two parameters that associates to damaged fruits percentage the impact damage probability depending on the impact level, suggested in paper [1], perfunctorily:

$$p = \frac{\exp(C + mX)}{1 + \exp(C + mX)} \tag{2}$$

where $p$ is the damage probability (decimally expressed); $X$ – the physical quantity which characterises the impact level; $C$, $m$ – logistic constants.

In our experiments, the impact level $X$ was characterised, in turn, by each of the physical quantities: $E_{ci}$ – initial impact kinetic energy (J); $v_i$ – initial impact velocity (m/s); $a$ – maximum indent radius of the fruit deformation during impact (mm), for the determination of the most suitable physical quantity which characterise the impact level in relation (2).

Relation (2) presents the benefit that the logistic parameters $C$ and $m$ can be determinate by laboratory experiments, where there are applied impacts of controlled and known levels $X$ on 'probe' fruit populations with an acceptable number of 70 – 100 fruits [1].

Based on experimental data, using specialized programs EXCEL, MahtCad or MicroCal Origin, it was tested the logistic function (2), was determinate the logistic constants $C$ and $m$, and was appreciate the concordance of the logistic function with the experimental data through the correlation coefficient value $R^2$, which had to be closer to unit. With the logistic constants $C$ and $m$ determinate from the experimental laboratory measurements, relation (2) is useful in two situations:

a) if it is imposed a reasonable admissible probability for the fruits impact damage (ex.: 0.05 or 0.10 [1, 14, 15, 18]), then from (2) it is obtaining the maximum impact level $X$, useful value in using the machinery adjustment and which can be calculated with the relation:

b)

$$X_{\max} = -\frac{1}{m}\left[\ln\left(\frac{1}{p_1} - 1\right) + C\right] \tag{3}$$

c) if in case of a sorting – packing machinery is known the impact level $X_l$ at which fruits can be subjected then, replacing the value in relation (2), it is predicted the fruits impact damage probability.

## 3. USED MATERIALS. APARATUS. MODE OF ACTION.

In experiments was used a 36 Jonathan apple population, manually harvested, from Voinești–Dâmbovița area, in an intensive and irrigated plantation, after a 6 months keeping time, in frigorific cells at a temperature of 3 – 4ºC at ICDVPH – RA Bucharest. Experiments were done in laboratory of Agricultural Machinery department of the Biotechnical Systems Engineering Faculty from University „Politehnica" of Bucharest in 1993. The experimental batch was divided in 4 groups of 9 fruits each one, which were subjected to 4 different impact velocities (respectively of 0.79, 1.0, 1.22 and 1.53 m/s), fruits from one group were impacted with the same velocity. The fruits impact was done through pendulum method on a pendulum apparatus realised in department laboratory by Professor T. Căsăndroiu. Details about this apparatus are given in [3, 4, 21]. After impact fruits were laid in 3 compartmented cardboard boxes, kept at room temperature (18 – 20ºC) and examined in impact area (marked on the fruit surface) 3 fruits from each group at intervals of 3, 5 and respectively 10 days after impact application. Examination was based on a visual analysis, with naked eye and with a 4X magnifying glass of the impact zone, out side as well as in section of the fruit's pulp for tracing out the bruised tissues, highlighted by apparition of the fruit's pulp colour modification. More details are available in [3, 4].

Before impact were measured the fruit's characteristic geometrical dimensions and weighted, and after impact was measured the maximum deformation indent diameter during fruit's impact recorded on paper. Based on apparatus calibration data were able to determinate, through calculation, the following quantities needed for the study: initial impact velocity ($v_i$), initial impact kinetic energy of the pendulum – fruit system ($E_{ci}$).

## 4. EXPERIMENTAL DATA. INTERPRETATION. COMENTS

Data obtained at experimentations on the 36 fruits batch, pre-processed on the form of average value ( $\overline{X}$ ) and standard deviations ($\sigma$) of the fruits masses ($m$), of the initial impact kinetic energies ($E_{ci}$), of the indent radius on the fruits' surface ($a$) at the 4 impact velocity levels ($v_i$), together with the percentage damage probability ($p$)

assimilated through the weight percentage of the damaged fruits in fruits number of each group, are synthetically presented in table 1.

Table 1. Average values ( $\overline{X}$ ) and standard deviations ($\sigma$) of the masses ($m$), the initial impact kinetic energies ($E_{ci}$) and the indent radius on the fruits' surface ($a$) for each of the four impact velocity levels ($v_i$), together with the percentage probability ($p$) of the damaged fruits.

| $v_i$ (m/s) | $m$ (g) | | $E_{ci}$ (J) | | $a$ (mm) | | $p$ (%) |
|---|---|---|---|---|---|---|---|
| | Average value*) | $\sigma$**) | Average value | $\sigma$ | Average value | $\sigma$ | |
| 0,79 | 145,6 | 16,0 | 0,101 | 0,005 | 8,1 | 0,3 | 22,2 |
| 1,0 | 156,1 | 13,1 | 0,172 | 0,006 | 9,4 | 0,5 | 33,3 |
| 1,22 | 145,6 | 5,9 | 0,241 | 0,004 | 9,7 | 0,2 | 44,4 |
| 1,53 | 126,7 | 6,0 | 0,352 | 0,006 | 10,3 | 0,6 | 77,8 |

*) $\overline{X} = \frac{\sum x_i}{n}$ ; **) $\left( \frac{\sum \left(x_i - \overline{X}\right)^2}{n-1} \right)^{1/2}$ , $x_i$ – current value; $n$ – measurements number

It comes out that at average values of the apples' masses in range of 126.7±6.0 g la 156.1±13.9 g, with the increase of the initial impact velocities level from 0.79 to 1.53 m/s, the average values level of the initial impact kinetic energies has increased from 0.101±0.005 to 0.352±0.006 J, the average values of the indent radius on the fruits' surfaces has increased from 8.1±0.3 to 10.3±0.6 mm, and the weight percentage of the damaged fruits has increased from 22.2 to 77.8 %.

Using the average values data from this table and the MathCad software on a PC XP, it was tested the logistic function (2) finding the logistic constants $C$ and $m$ for each one of the physical quantities $E_{ci}$, $v_i$, $a$ used for the characterisation of the impact level $X$ from relation (2) and respectively the correlation coefficients $R^2$. The values for these constants are given in table 2.

Table 2. The logistic constants values $C$ and $m$ for each one of the physical quantities $E_{ci}$, $v_i$, $a$ used for the characterisation of the impact level $X$ from relation (2) and the adequate correlation coefficient $R^2$.

| $X$ | $E_{ci}$ | $v_i$ | $a$ |
|---|---|---|---|
| $C$ | - 2,428 | - 4,069 | - 12,134 |
| $m$ | 9,939 | 3,336 | 1,251 |
| $R^2$ | 0,976 | 0,967 | 0,833 |
| $\chi^2$ | 0,0021 | 0,00285 | 0,0145 |

From examination of the correlation coefficient values $R^2$ and the $\chi^2$ test, it comes out a good concordance of the obtained experimental data from the logistic function (2) and the utilisation as physical quantities for the impact level characterisation of the $E_{ci}$ or $v_i$ for which $R^2 \geq 0.967$. Because of that the physical quantity $E_{ci}$ is more adequate for the impact level characterisation ($R^2$ = 0.967), being a physical quantity more complex because includes implicitly the fruit's mass and its impact velocity.

Variation of apple impact damage probability described by relation (2) for the logistic constants values from table 2 in three situations characterising the impact level, related to experimental data is graphically presented in figure 1 (a, b, c), in which the validity domain was extrapolated. Also from the data examination given in table 2, diagram from figure 1(a), in comparative with the others, has the best concordance for the experimental data with the logistic function (2), for the impact level characterised by the initial impact kinetic energy $E_{ci}$. The logistic function drawn in figure 1(a) can be used for obtaining the answers to the two problems a) and b) formulated in §2.

In this case it comes out the relation for prognosis of the impact probability on rigid surfaces, for Jonathan apples, after a 6 months keeping time in frigorific cells, being described by the equation:

$$p = \frac{\exp\left(-2{,}428 + 9{,}939 E_{ci}\right)}{1 + \exp\left(-2{,}428 + 9{,}939 E_{ci}\right)} \tag{4}$$

in which $E_{ci}$ is initial impact kinetic energy in J.

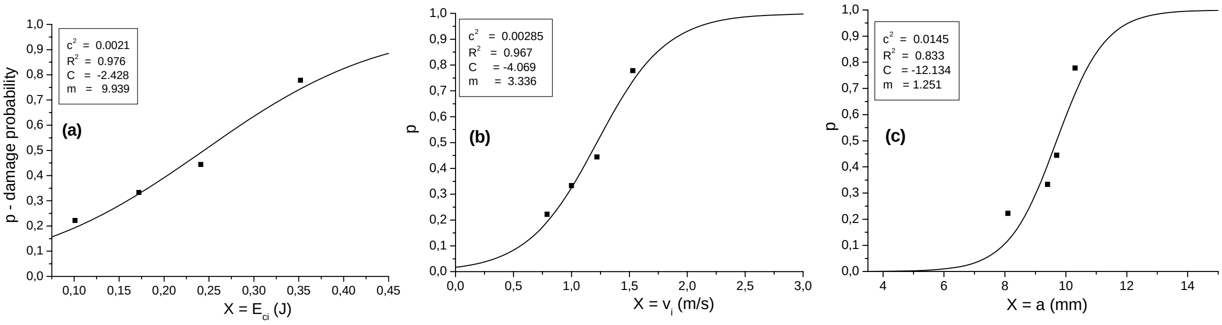


Fig. 1. Concordance between logistic curves with experimental data in Jonathan apple case for the three physical quantities defining the impact level, ■ – experimental points, ▬ – logistic curve

Impact damage probability value ($p$) expressed by relation (4) can be assimilated with the damaged fruits weight (expressed decimally) from the impacted fruits number (population) at the initial impact kinetic energy level $E_{ci}$ (J) for a reliable level value of 95%, [1].

Relation (4) is useful in two practical situations:

a) if we impose an admissible damage weight of 10% ($p$ = 0.1), using relation (3) and after making the calculations, it comes out $E_{ci\ max}$ = 0.023 J, which means that for $E_{ci} \leq 0.023$ J it results an damaged fruits weight of $p \leq 10\%$. Value $E_{ci}$ = 0.23 J can be used either in design, or in correct choosing of the working kinematical parameters of an apple sorting – packing installation;

b) for the initial impact kinetic energy value $E_{ci}$ = 0,05 J [1, 3, 4] for which appear the first bruises of the pulp tissue observed in experimentations, from relation (4) it comes out that $p$ = 0.127, meaning a damaged fruits weight of at maximum 12.7%. At an kinetic energy level of $E_{ci}$ = 0,02 J it results $p$ = 0,097, respectively 9.7%, if it is admitted that relation (4) can be extrapolated outside the $E_{ci}$ values domain from the experimentations.

**Observations from the experiments** [3, 4]**.** At the examination of the impacted area, for the lowest level of the initial kinetic energy ($E_{ci}$ = 0.085 J) it was noticed to some fruits the apparition in section of a tissue bruise at 1.5 – 2.5 mm under the epidermis. Due to impact, together with the compressive stresses appear the shearing stresses whose maximum value (in case of elastic impact) is manifested under epidermis at approximately 0.48$a$ [12]. This fact suggested a possible explication for the tissue bruise apparition under epicarp due, principally, to the shearing stress which can produce slides between cellular layers, determining shearing (ruptures) of those (although these represent approximately 0.27 from maximum normal compression stresses) [12], fact confirmed by out experimentations. A possible explanation consists in that the cellular tissues sustain much easier the normal compression stresses in comparison with tangent shearing stresses. These ruptures develop in time causing deterioration of the adjacent tissues leading to fruit's qualitative depreciation. For $E_{ci}$ = 0.085 J [3], from relation (4) it comes out that $p$ = 0.17, respectively 17%, a potential damage probability value.

## 5. CONCLUSIONS

Our researches shows that the apple impact damage probability depending on impact level, for Jonathan variety, can be well described through a 2 parameters logistic function in form of relation (2). It was determinate that impact level can be properly characterised by impact kinetic energy $X = E_{ci}$. For this situation were determinate logistic parameters to a correlation coefficient $R^2$ = 0.967 and was found the relation (4) for the prediction of the potential impact damage probability for a given impact level $E_{ci}$. Relation (4) can be useful in design activity of the technical systems for sorting – packing of apples, as well in rational use activity of those.

For other fruits varieties there can be determinate similar relations through the logistic parameters evaluation from relation (2) after the methodology presented in this paper. Also, was define the impact damage susceptibility coefficient, a quantity which express more adequate and shaded the impact bruise, by introducing in appreciation the natural variability of the fruit's mechanical and physical characteristics through the probabilistic interpretation of the impact damage phenomenon. In Jonathan apples case, impact damage susceptibility coefficient value is $E_{ci}$ = 0.023 J corresponding to an impact damage potential probability of $p$ = 10% (accepted value in accordance with E.U. standards [1, 14, 15, 18, 19]).

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