FRUIT FIRMNESS AND SKIN RESISTANCE OF PROCESSING TOMATO VARIETIES TESTED IN BADAJOZ (SPAIN), RELATED TO MECHANICAL HARVESTING

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Abstract

Determinations of resistance to damage were carried out in a total of 31 tomato varieties for processing, with the purpose of choosing the most suitable ones for mechanical harvesting. The characteristics studied include: puncture, deformation and rupture of the fruits, the ease of detachment of the fruits also being determined. Seventeen varieties were chosen, for further tests, with values 0.76 to 1.72 N of resistance to puncture; 3 to 9 N/mm of resistance to compression and 2.16 to 29.40 N resistance to detachment.

Introduction

Complete mechanization of the cultivation and harvesting of tomatoes for processing is already a fact. Due to this, when testing varieties for their possible introduction in the area of Las Vegas del Guadiana it was necessary to take into account their characteristics of resistance to mechanical harvesting and transport. In order to do so, the techniques applied were for the main part, those previously used in laboratory and field tests (Altisent, M.R., 1975) and which are based fundamentally on three properties:

- Resistance to the external puncture of the fruit
- Resistance to deformation (indeformability or firmness)
- Force of detachment and percentage of fruits with peduncle

At the same time tests were also carried out on the resistance to rupture through impact (free falling). In this paper the results of these properties are presented in those tomato varieties corresponding to the same test which, in its aspect of agronomic characteristics, were carried out by the fourth author in a parallel work. This work would not have been possible without the collaboration of the Madrid firm CARCESA and the Service of Agricultural Extension of Don Benito, whose installations and material means have been used in various stages of the same.

Materials and methods

Puncture

The technique described in (1) was used, consisting in

puncture by means of a Chatillon table dynamometer (figure 1), whose platform rises at a speed which may be regulated by means of an electric motor. By always using the minimum speed (4 cm/min) and by means of a cylindrical die with a flat base, 0.45 mm in diameter, the maximum force in the rupture of the shin was determined in five points of the equatorial area of the fruit, ten fruits per variety being tested. A dynamometer of maximum force of 1 kg (9.8 N) was used.

Relation force-deformation

Using the dynamometer mentioned above, provided with a flat disk (figure 2), and at the minimum rising speed of the platform, various points of compression force (N) were determined and the corresponding deformation (in mm) for each of the fruits. At the said points a straight line is adjusted through regression, whose slope or coefficient of regression b provides a value of the resistance to deformation or firmness of the said fruit. We also determined in the fruits:

- the surface of contact (maximum and minimum diameters) indicated by the point, on applying talcum powder to the compression plate.
- The mass, in grammes.
- The damage produced in 10 fruits that were allowed to drop one by one from a height of 70 cm.

Force of detachment

By means of several manual spring dynamometers of 0.5 to 5 kg of maximum force (5-10 N), the force of detachment (f.d.) was determined in a total of 20 fruits (40 measurements) per variety, in two directions:

- according to the longitudinal direction of the stem
- transversally, that is, by applying a torque with respect to the point of loosening (peduncle or join), at a distance of approximately 1 cm.

The measurements were carried out in the same plot, avoiding the extreme times of day with regards to heat and humidity. In the analysis of the results, the data of an average number of peduncles in 100 fruits of each variety have been used, determined in the harvesting of the pertinent plot (Rodriguez del Rincon, A., Altisent, M.R., 1979).

Results and discussion

Resistance to puncture

Having carried out the analysis of variance (for a total of 1 550 measurements in the test of 31 varieties without repetition and 890 in the test of nine varieties with repetition ("high" (26-30ºC) and "low" (20-25ºC) temperatures)), the following results were obtained: the average values of resistance to puncture are given in detail, ordered from greater to lesser, in table 1, a highly significant ef-

fect, due to variety, having resulted in the analysis of variance. The representation in Duncan test bars shows the existence of some groups of extreme varieties (of high and low resistance to puncture respectively) and an intermediate group of some twenty varieties without great differencies (also see fig. 3). The result of the second analysis shows that the effect of replication and, therefore, in this case, of the temperature variation (3 to 8ºC) is not significant. However, ther appear to be important differences in various senses, for some of the varieties (table 2). This point will be the object of a detailed study later as it seems clear, in the laboratory tests, that the temperature does influence resistance to puncture in an important way. A significant effect due to fruit appeared, just as has been repeatedly observed in the experiments carried out previously: the variability among fruits within the same variety is important. It may be attributed to differences in maturity, insolation and others, but in any event, this variability is found in effect in the crop.

Resistance to compression

The average values of resistance to compression (force-deformation) in terms of b for the 31 varieties tested are laid out in table 3. Carried out in this way, this test discriminates less among the varieties (a higher error than in the values of puncture, due to a lower number of measurements), although the order in which they appear is consistent with previous results. Table 4 shows the results of the test of 9 varieties with repetition. Important differences may be observed for some varieties, which may be related in some cases with the difference in temperature (Peto Early and Roma, 2nd repetition 8ºC hotter), but not in the rest. The analysis of variance does not show any significance for the effect of repetition, so that the valid averages are the total ones. There is no significant correlation between the varietal averages not of fruits, nor strength of puncture and resistance to compression. That is to say that, in homogenous conditions, the resistance to puncture and resistance to compression are indepent. However, the environmental conditions tend in some cases to make them vary in the same cases.

Resistance to damage through impact

The results of the test of impact through falling are shown in table 5. Having found the correlations between index I (sum of the number of fruits which crack plus the number of fruits with severe damage) and the average varietals of mass, force of puncture and firmness, the following indications are obtained:

- a large part (35%) of the variability in index I of damage through falling may be applied to the variations in the average mass of the fruits;
- another important part (22%) may be applied to the variation in the average value of force of puncture and only 2%

to the differences in firmness.

Figure 3 shows, in the lower part, the average values of resistance to puncture for the 31 varieties tested, placed in an increasing order; in the upper part, the indeces of rupture through impact pertinent to each of these varieties are shown. The tendency for the index of rupture to diminish when the resistance to puncture increases may be observed. The obvious deviations observed are related with a very high average mass of the fruits or with a very low firmness. From all this one may deduce again that the puncture is more suitable than that of compression to predict the resistance to impacts of tomatoes. It may be affirmed that varieties with both high values are resistant and varieties which have both the values low are very susceptible to mechanical damage. In the other cases, fruits with a high resistance to puncture are the most resistant.

2) Varieties with very low percentage of peduncles (l.p. in table 6)

Variety	average f.d. in peduncle (N)		average f.d. joint (N)		% fruits with peduncle
	parcial (a	total (b	parcial (a	total (b	
Nova Super Roma	3,92	6,88	2,94	4,95	5,3
H-324-1	3,04	3,63	2,94	3,87	5,6
VF-65	0,01	1,62	1,47	5,64	9,3

a) corresponds to those fruits which loosened by the peduncle or by the joint respectively.
b) corresponds to the 10 fruits measured.

They all show some of the lowest forces of loosening of those measured, both in the peduncle and the joint. These kind of varieties are the most interesting, and not only that of "joint-less" varieties, as the few peduncles which remain are always easy to eliminate, even simply by the movement of the fruits in the machine, in the conveyor and in transport.

3) Varieties with the highest percentages of peduncles (h.p. in Table 6)

Variety	average f.d. peduncle (N)		average f.d. joint (N)		% fruits with peduncle	Diference f. d. (N) ped.	joint
	Parcial (a	total (b	Parcial (a	Total (b		Parcial (a	Total (b
ES 58	10,00	14,70	1,96	8,53	80	8,04	6,17
Bulker it	19,60	20,09	17,96	--	79,3	1,60	--
Bulker USA	15,44	21,17	12,08	18,52	72,6	3,35	2,65
C 35	11,76	17,15	8,09	9,02	72,3	3,68	8,13
H 530	19,28	19,70	6,44	9,21	68,3	12,84	10,49

In this group very high forces of detachment are observed, combined with important differences between the averages of peduncle-joint, in favour of the former. The varieties belonging to this group are those which evidently cause more problems at the time of mechanical harvesting. All those varieties with high f.d. in the peduncles (as from some 10 N) will be aqually problematic, independent of the f.d. in the joint; evidently the problem will be the greatest on combining with a low, or considerably lower f.d. in the joint. Finally the correlations have been calculated between the percentage of fruits with peduncle and the average values of those characteristics indicated below (for the 26 joint--less varieties):

- f.d. peduncle : r = 0,69**
- f.d. joint : r = 0,55**
- difference f.d. peduncle-f.d. joint : r = 0,57**

(**: significant at the 99% level).

Force of detachment and percentage of peduncles of the fruit

In mechanical harvesting it is highly desirable, almost indispensable, that the tomatoes come out of the harvester without peduncles. These are the cause of two problems: on the one hand, they damage the adjacent fruit during transport, unloading and the entrance to the factory; afterwards it is necessary to eliminate them manually on the classification table, with a high labour cost. The results for the different varieties relative to the force of detachment f.d., and percentage of peduncles of the fruit is shown in Table 6. There only the most significant data have been chosen: average value of f.d. in the peduncle (joining with the fruit) and the average value of f.d. at the joint, both in a longitudinal direction. The measurements in a transversal sense were problematic, and in some cases with erratic values. The percentages of fruits with peduncles observed in harvesting are included in the table. Conclusions may be obtained on observing the results of three defined groups of varieties:

1. Those classified as "without a joint".
2. Those with a joint, but with very low percentages of fruits with a peduncle.
3. Those which have very high percentages of peduncles.

1) Varieties whose fruits loosened at the peduncle and which had no observable area of joint (j.l. in Table 6)

Variety	average f.d. in peduncle (N)	% fruits with peduncle
H-30	29,4	19,6
Florida MH-1	16,22	15,6
Río Grande	12,84	1,3
H-4016	11,37	3,0
Cal J	9,65	5
Europeel	9,46	1,3

In these varieties extremely small percentages of fruits with a peduncle are observed, except for the two varieties H-30 and Florida MH-1 which show, in spite of their lack of a joint, a higher percentage of peduncles. It may be observed that these have the highest values (the highest of all the varieties measured in the case of the H-30) of detachment force; this is the reason that some fruits maintain fragments of branches (which is as much of a problem as the peduncles) (see figure 4). Another fact observed is the variable expressivity of the character, "joint-less" in the different plants of some varieties, all giving significant results (also for partial values). That is, the greater the force of detachment in these points (and their difference) thus measured, one must expect a greater percentage of peduncles in the fruits on harvesting. In figure 4 it may be seen how the percentage of peduncles tends to increase in a parallel way to force loosening of the same. The six points which are significantly displaced correspond exactly to the five joint-less varieties. In figure 5 the f.d. of the peduncle and the joint are shown in relation to the percentage of peduncles. The two f.d.'s are very similar, the one corresponding to the joint (the broken line) in general being lower; and significantly lower in the varieties with a high percentage of peduncles (the right area of the graph). With respect to the measurements in a transversal sense, and only taking into account those carried out in the form a (26 varieties, see Materials and Methods) it has been observed that the force is always lower (in effect it is a moment of loosening, the force being situated at a distance of 0.-1 m from the point of breaking), both in the joint and in the peduncle. Its correlation with the percentage of peduncles in the fruits is less noticeable than in the case of the longitudinal forces. This is logical, due to the greater variability and difficulty in the transversal measurements, and also to the small number of measurements (this last fact is applicable to all data of detachment).

Conclusions

Finally, in the way of conclusions, Table 7 shows the varieties whose characteristics of resistance, in these prior tests, make them more suitable for mechanical harvesting. This is independent of the agronomic or industrial characteristics which may be negatively or positively (which were studied in (2)), and which constitutes only a first elimination of varieties, for a more exact tests which will be carried out next season. The table includes the ten best varieties chosen separately for each one of the characteristics studied, eliminated three of them due to some characteristics specially unfavourable. (see Tables 1, 3, 5 and 6).

Summary

The complete mechanization of the cultivation and harvesting of tomatoes for processing is already a fact. Due to this, on having to test varieties for their possible intro-

duction in Las Vegas des Guadiana (Badajoz, Spain), it was necessary to take into account their characteristics of resistance to mechanical harvesting and transport. In order to do so, tests were carried out, applying the techniques previously developed, to determine the resistance of the fruits to puncture and compression, related with the effect produced in the same by impacts. With respect to the resistance to puncture, very significant differences were observed among varieties, with average values running from 0.8-0.9 N (for Bulker and ES-58) to 1.72 N for Petogro II. The relationship between these values and the susceptibility to rupture of the fruits (shown by other authors in a number of works) became evident in these tests. The differences between the average varietal values of resistance to compression (established as the slope of the straight line adjusted to the points of force and deformation) were also significant. The influence of the environmental conditions and of other factors determine a greater variability and, thus, a more difficult varietal determination of these characteristics. The average values obtained vary between 8-9 N/mm for Peto Early and Cal-J and 3 N/mm for Chico III and Napoli. The combination of high values in both characteristics (puncture and firmness) gives the fruits resistance to rupture. The force of detachment of the peduncles is an important characteristic in those varieties of tomato for mechanical harvesting in several different aspects: ease of detachment in the shaking elements of the harvester; damage produced by the peduncles of some fruits to the adjacent ones and the problem of eliminating the peduncles on reaching the factory. All this is determined by the force necessary for loosening in the two points ("peduncle" and "joint) and its relative values. The measurements carried out show very important differences in the average values of the forces indicated for the different varieties (between 2 and 30 N for the peduncle in a longitudinal direction), which are related to the percentage of fruits with a peduncle in harvesting.

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Table 1 - Resistance to puncture of 31 varieties. Average value of 50 determinations and the Duncan test. (Varieties grouped in the same bar do not show significant differences at the level of 1 per cent). Coefficient of variation=0.14. Typical error of the means=0.03 N.

Variety	mean f.p. (N)
Petogro II	1,72
Petomech	1,52
Ventura	1,45
Euromech	1,42
Cal J	1,42
Peto Early	1,34
Europeel	1,25
H-30	1,25
Hypeel 229	1,23
Royal Chico	1,21
VF-65	1,20
Florida MH-1	1,18
H-4016	1,18
H-324-1	1,17
California	1,16
Río Grande	1,16
Cambella 147/73	1,15
Napoli	1,12
C-34	1,11
Nova Super Roma	1,10
H-1706	1,07
Chico III	1,06
Super California	1,06
C-35	1,05
Super Roma	1,05
Roma VF	1,04
Dorchester	1,00
H-2274	0,96
H-530	0,91
ES-58	0,89
Bulker	0,76

Table 2 - Resistance to puncture of 9 varieties with repetition (50 determinations in each repetition)

Variety	total mean f.p. (N)	mean 1st rep(N) (low temperat.)	mean 2nd rep. (N) (high temperat.)
Cal J	1,56	1,71	1,42
Petomech	1,49	1,53	1,44
Peto Early	1,38	1,34	1,44
H-324-1	1,24	1,31	1,17
Ventura	1,24	1,45	1,03
H-30	1,21	1,25	1,16
Super-Roma	1,06	1,05	1,08
Roma VF	1,04	1,04	1,04
Dorchester	1,03	1,00	1,07

Table 3 - Resistance to deformation (N/mm). Average value of the coefficient b of 10 fruits and Duncan test. Coefficient of variation = 0,23. Typical error of the means = 0,36 N/mm

Variety	Mean value of firmness coefficient b (N/mm)
Peto Early	9,00
Cal J	8,20
Río Grande	7,38
H-4016	7,29
Petogro II	6,68
Petomech	6,46
Europeel	6,30
Florida MH-1	6,11
ES-58	5,83
Euromech	5,69
H-530	5,65
H-30	5,40
Roma VF	5,28
Nova Super Roma	5,13
H-1706	5,09
Hypeel 229	4,39
Bulker	4,27
California	4,27
Dorchester	4,27
VF-65	4,25
Super California	4,24
H-324-1	3,97
H-2274	3,89
Royal Chico	3,89
C-34	3,57
Ventura	3,22
C-35	3,17
Cambella	3,13
Super Roma	3,05
Napoli	3,03
Chico III	2,99

Table 4 - Average values of force-deformation (N/mm) for 9 varieties with repetition

Variety	total mean b (N/mm)	mean 1st rep. (N/mm)(low temp)	mean 2nd rep. (N/mm)(high temp) (1)
Peto Early	6,83	8,95	4,19
Cal J	6,56	8,20	4,91
H-30	6,15	5,40	6,90
Petomech	6,01	6,46	5,56
Dorchester	4,60	4,27	4,94
Roma VF	4,05	5,28	2,81
H-324-1	4,02	3,97	4,08
Super Roma	3,29	3,54	3,05
Ventura	3,26	3,22	3,30

(1) Overmature

Table 5 - Susceptibility to free fall impact indeces (I=nº of cracked fruits plus severely damaged fruits) for 30 varieties, in relation to mean mass (g) mean puncture resistance (N) and firmness(N/mm) (10 fruits/variety)

Variety	Index I	mean mass (g)	mean puncture resistance(N)	firmness (N/mm)
Cal J	0	69	1,42	8,20
Petogro II	1	70	1,72	6,68
Petomech	1	62	1,45	6,46
Rio Grande	1	93	1,16	7,38
Euromech	2	59	1,42	5,69
Royal Chico	2	58	1,21	3,89
Super California	2	52	1,06	4,24
Nova Super Roma	2	51	1,10	5,13
H-1706	2	52	1,07	5,09
Hypeel 229	2	51	1,23	4,39
H-324-1	3	49	1,17	3,97
H-30	3	111	1,25	5,40
California	3	53	1,16	4,27
Super Roma	4	55	1,05	3,05
Ventura	4	46	1,45	3,22
Dorchester	5	58	1,07	4,27
H-4016	6	59	1,18	7,29
C-35	7	85	1,05	3,17
Europeel	7	60	1,25	6,30
Peto Early	7	89	1,34	9,00
Napoli	7	55	1,12	3,03
H-2274	9	115	0,96	3,89
Roma VF	9	63	1,04	5,28
C-34	9	77	1,11	3,57
H-530	12	138	0,91	5,65
Chico III	12	57	1,06	2,99
Bulker	13	129	0,76	4,27
Florida MH-1	14	115	1,18	6,11
ES-58	19	170	0,89	5,83
Cambella	20	68	1,11	3,13

Table 6 - Average values of force of detachment (f.d.) measured in a longitudinal direction of the peduncle and joint, and average percentage of fruits with a peduncle on harvesting.

Variety	f.d.longitud. in peduncle(N)	f.d. longit. in joint (N)	% of fruits with peduncle
Europeel (j.l.)	9,46	-	1,3
Río Grande(j.l.)	12,84	-	1,3
H-4016 (j.l.)	11,37	-	3,0
Cal J (j.l.)	9,65	-	5,0
Nova Super Roma (l.p.)	6,88	4,95	5,3
H-324-1 (l.p.)	3,63	3,87	5,6
VF-65 (l.p.)	1,62	5,64	9,3
H-30 (j.l.)	29,40	-	19,6
Florida MH-1 (j.l.)	16,22	-	15,0
Euromech	11,17	11,56	21,6
Petomech	10,00	6,13	22,6
Napoli	8,04	3,46	29,0
Royal Chico	5,26	3,72	33,0
Super California	2,45	4,80	33,0
Hypeel 229	4,51	9,41	33,5
Cambella 147/33	5,49	4,75	35,5
Roma VF	3,97	6,22	39,3
C-34	11,86	7,45	42,6
Super Roma	6,57	5,05	43,3
H-1706	3,19	3,63	46,0
Petogro II	7,49	5,46	46,6
Dorchester	2,16	6,37	49,6
Ventura	6,96	6,96	50,0
Peto Early	11,76	11,96	53,0
California	8,33	3,63	55,3
Chico III	5,39	5,10	55,6
H-2274	16,32	10,63	57,3
H-530 (h.p.)	19,70	9,21	68,3
C-35 (h.p.)	17,15	9,02	72,3
Bulker (h.p.)	21,17	18,52	72,6
ES-58 (h.p.)	14,70	8,53	80,0

Table 7 - Characteristics of the 17 best varieties chosen on the basis of their suitability for mechanical harvesting.

Variety	Resistance to puncture	firmness (N/mm)	rupture index by impact	detachment force of peduncle (N)
Petogro II	1,72	6,88	1	7,94
Petomech	1,52	6,46	1	10,00
Ventura	1,45	3,22	4	6,96
Euromech	1,42	5,69	2	11,17
Cal J	1,42	8,20	0	9,65 (j.l.)
Peto Early	1,34	9,00	7	11,76
Europeel	1,25	6,30	7	9,46 (j.l.)
H-30	1,25	5,40	3	29,40 (j.l.)
Hypeel	1,23	4,39	2	4,51
Royal Chico	1,20	3,89	2	5,26
Rio Grande	1,16	7,38	1	12,84 (j.l.)
H-4016	1,18	7,29	6	11,37 (j.l.)
VF-65	1,20	4,25	0	1,62
Dorchester	1,00	4,25	1	2,16
Super California	1,06	4,24	2	2,45
Nova Super Roma	1,10	5,13	2	6,88
H-324-1	1,17	3,97	3	3,63

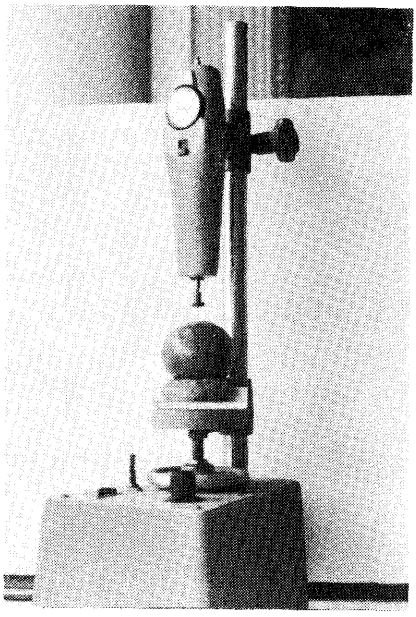

Figure 1 - Chatillon table dynamometer

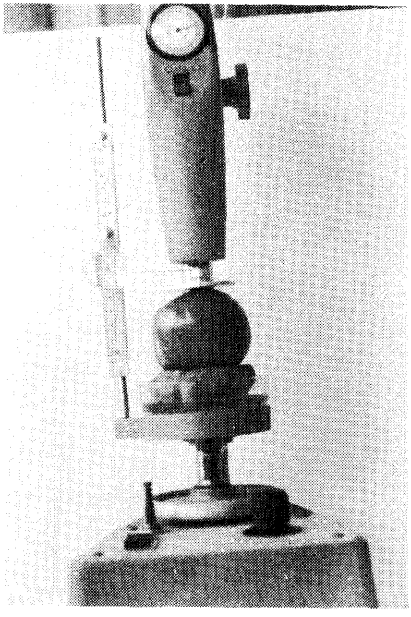

Figure 2 - The same, with a flat disk

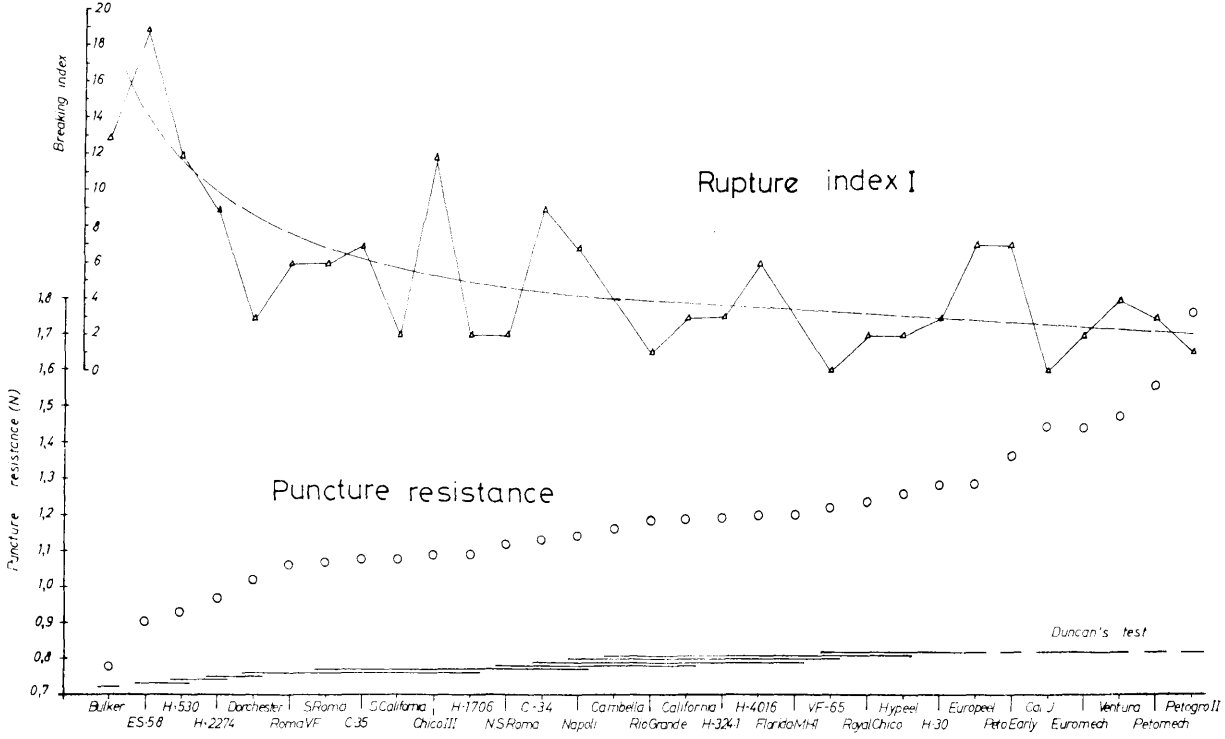

Figure 3. - Average values of resistance to puncture and rupture index of the 31 varieties tested.

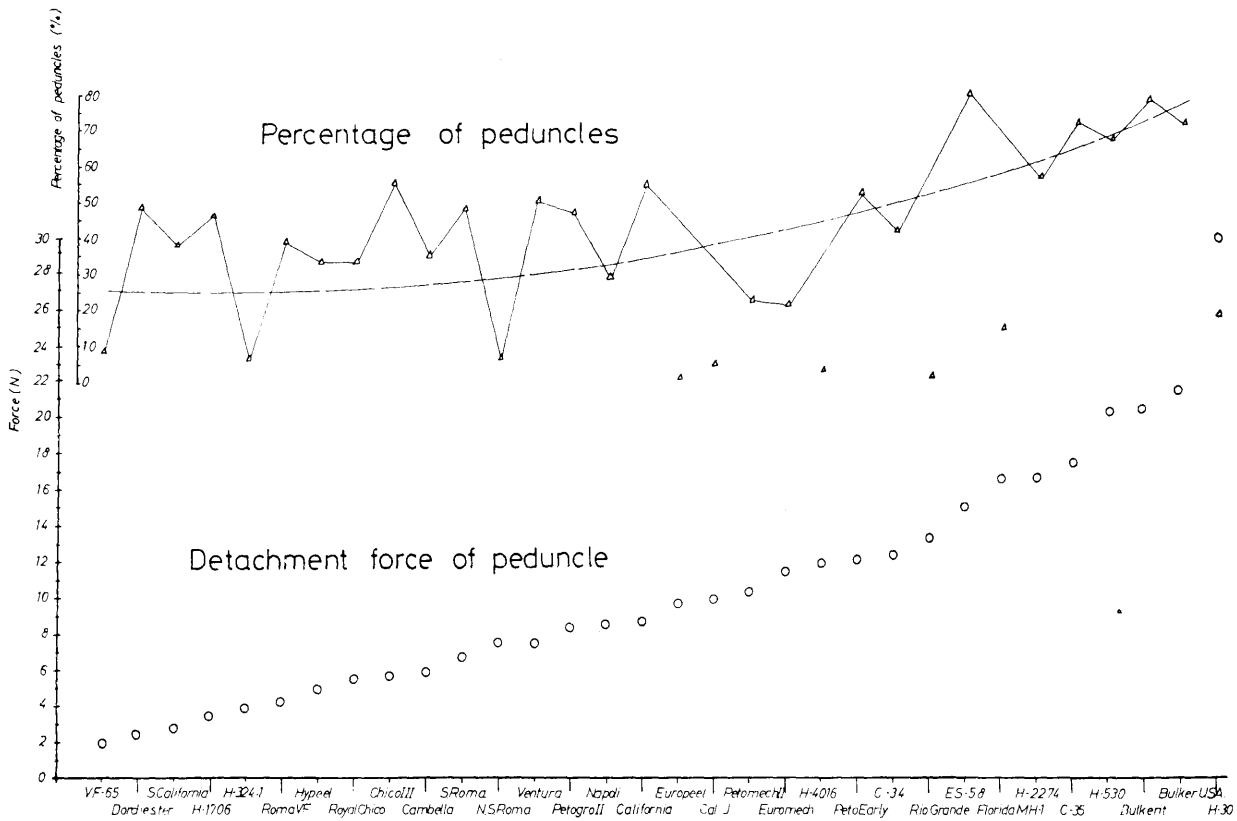

Figure 4.- Average values of detachment force and percentage peduncles in the 31 varieties tested.

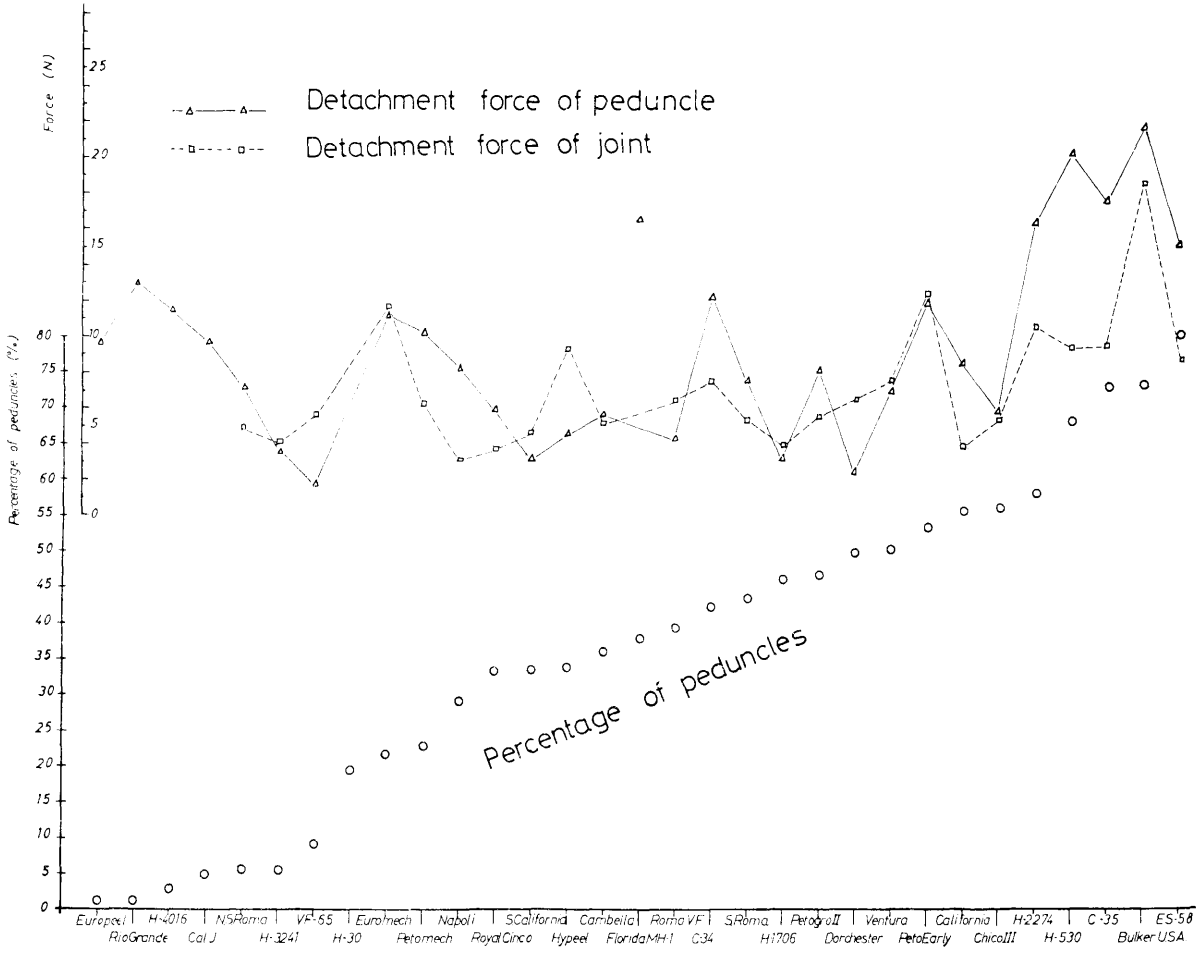

Figure 5. - Percentage of peduncles and forces of detachment in the peduncle and joint.