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ROLE OF SKIN IN COMPRESSION OF BERRY-LIKE FRUITS BETWEEN TWO PLATES

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A b s t r a c t. Berry-like fruits of cultural plants (currant, vine grapes, aronia) and natural growing plants (lilac elder, rowan berry, bilberry, cowberry, cranberry) were tested by compression between two plates in time of their maturity. Moreover, currant berries were compressed repeatedly for five weeks (before and after the picking maturity). It was found that compression curves are composed from two simple parts, that can be described by power relations $\alpha = a\varepsilon^n$, where a and n are parameters, typical for every different part, different berries and different stage of maturity. Strength of berries generally decreases in time of maturity and in the same time the maximal relative deformation of the tested berries increases at first and decreases later (ε_m=0.35-0.47). The strength of the tested berries has been taken as a basis for estimation of maximum meridian stress in the berries skin. The obtained results are comparable with the strength of a tomato skin, that have been determined in direct tension test of samples prepared from the skin by cutting.

K e y w o r d s: berry-like fruits, compression

INTRODUCTION

One source of skin cracking at berry-like fruits is pressure contact of other bodies, that is very frequent during fruit harvesting, transport, storage, and processing. The external pressure contact causes skin tension and so manner cracking of skin. Probability of fruit skin cracking under of such type loading is influenced not only by the external forces, but also by mechanical properties of the skin. It seems that tension stress in the skin of a compressed fruit is a power function of relative compression deformation of the fruit [1,3].

This paper is an experimental study of mechanical properties of different berry-like fruits during their compression between two plates with the aim to find parameters describing the compression curves for the different sorts of berries and the different stages of their maturity.

MATERIALS AND METHODS

At least 20 fruits of every variety have been measured. Experimental material has been obtained from different places: harvested in University orchard and garden or picked in forest. Fruits have been harvested in stage of full maturity (in most of cases) or periodically in different stages of maturity (currant). Experiments have been performed in short time after the picking (within 24 h after picking). Mean radius *r*, dry matter content *c*, index of refraction (°Brix) and thickness of skin *t* has been determined for every variety (Table 1).

Figure 1a contains a scheme of the test to be used. Every tested fruit was placed on a hard plate and then it was compressed by another plate using the deformation machine HECKERT FPZ 10/01. Velocity of plate was about 0.5 mm s^{-1} and motion was stopped after the cracking of the fruit. The obtained deformation curves have the typical shape (Fig. 1b) and they are represented by the relation of deformation force *F* and compression deformation *x*. They end by cracking behaviour of the fruit skin at values

Table 1. Tested products

Product and variety	Date (1992)	Moisture content (%)	Fruit radius r (mm)	Refract index (°Brix)	Skin thickness t (mm)
Red currant					
(Ribes rubrum)					
var. Bohemia	16.6	85.1	4.3	11	0.055
	19.6	85.1	5	11.2	0.055
	25.6	83.3	4.8	11.5	0.05
	1.7	83.3	5.3	11.5	0.05
	7.7	83.2	5.7	11.7	0.05
var. Heinemann	16.6	88.3	4.5	7.5	0.075
	19.6	87.8	4.8	7.9	0.075
	25.6	87.6	4.6	8.5	0.075
	1.7	87.6	4.5	8.8	0.075
	7.7	86.9	4.8	8.9	0.07
var. Jonkheer van Tets	16.6	86.2	4.9	9.6	0.065
	19.6	84.5	5.0	11.0	0.065
	25.6	84.1	5.0	11.2	0.055
	1.7	83.5	5.1	12.0	0.05
	7.7	82.6	5.2	13.2	0.05
Black currant	16.6	81.5	4.6	12.5	0.105
(Ribes nigrum)	19.6	79.5	4.5	12.7	0.105
var. Otelo	25.6	79.1	4.8	12.9	0.10
	1.7	78.5	5.0	16.5	0.10
	7.7	78.6	5.0	17.0	0.10
Elder-berry	13.8	79.3	2.55	15.5	0.053
Sambucus nigra L.					
Bilberry	25.8	86.5	4.40	13.5	0.050
Vaccinium myrtillus L.					
Cowberry	25.8	85.3	4.25	15.5	0.055
Vaccinium vitis-idaea L.					
Cranberry	21.9	88.5	4.8	9.5	0.085
Oxycoccus quadripetalus L.					
Rowan berry					
Sorbus aucuparia L.					
Subs. Moravica	25.8	71.5	5.00	-	0.100
Aronia var. Nero	25.8	82.4	4.80	-	0.134
Sorbus melanocarpa Wild.	11.8	74.6	3.00	21.0	0.060
Grape					
Vitis vinifera L.					
var. Ryzlnik		81.7	6.50	19.3	0.115
var. Burgundy		76.1	6.00	25.4	0.150
var. Müller-Thurgau		77.0	7.00	22.7	0.115

$x = x_m$ and $F = F_m$. Simple points of the deformation curve have been evaluated by a computer, working on line with the deformation machine. For careful determination of point of the contact between the tested fruit and the moving plate the optical observation of a slot between the fruit and plate has been used.

For simple points of the evaluated deformation curve the tension stress was computed from compression force F under an assumption that the flesh of the fruit does not contribute to the mechanical resistance of the

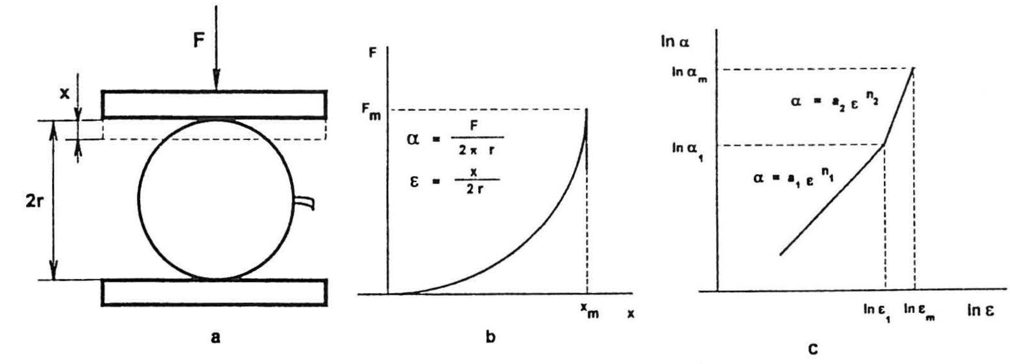

Fig. 1. Compression test of a product between two plates: a - schema of the test; b - dependence of the compression curve on the compression deformation, F_m and x_m are coordinates that correspond to the product rupture; c - compression curve plotted in transformed coordinates.

Table 2. Parameters of tested fruits

Product and variety	Date	ε_m	ε_1	α_m (N/mm)	α_1 (N/mm)	a_1 (N/mm)	n1	a_2 (N/mm)	n2
Red current									
Bohemia	16.6	0.362	0.168	0.780	0.355	3.88	1.32	2.190	1.028
	19.6	0.385	0.216	0.568	0.266	3.11	1.56	1.792	1.225
	25.6	0.433	0.337	0.148	0.090	0.55	1.70	0.779	2.029
	1.7	0.335	0.159	0.082	0.024	0.32	1.41	0.510	1.664
	7.7	0.313	0.126	0.074	0.017	0.25	1.30	0.484	1.622
Heinemann	16.6	0.362	0.152	0.569	0.249	2.92	1.30	1.457	0.947
	19.6	0.383	0.211	0.460	0.214	2.87	1.63	1.506	1.290
	25.6	0.391	0.246	0.387	0.207	2.01	1.55	1.323	1.391
	1.7	0.427	0.146	0.227	0.029	0.53	1.48	1.145	1.900
	7.7	0.387	0.167	0.155	0.034	0.56	1.58	0.758	1.743
Jonkheer v. T.	16.6	0.405	0.282	0.355	0.211	1.50	1.55	1.381	1.566
	19.6	0.442	0.326	0.261	0.138	1.09	1.69	1.349	2.079
	25.6	0.315	0.193	0.079	0.034	0.44	1.56	0.631	1.763
	1.7	0.403	0.251	0.125	0.052	0.39	1.51	0.688	1.923
	7.7	0.366	0.126	0.980	0.018	0.29	1.34	0.470	1.582
Britania	7.7	0.427	0.166	0.841	0.202	1.6	1.13	3.047	1.472
Black current									
Otelo	16.6	0.381	0.219	0.234	0.102	1.03	1.44	1.051	1.482
	19.6	0.350	0.201	0.204	0.088	0.91	1.42	1.180	1.560
	25.6	0.349	0.199	0.115	0.050	0.49	1.41	0.621	1.510
	1.7	0.379	0.226	0.092	0.042	0.40	1.49	0.429	1.581
	7.7	0.273	0.136	0.040	0.017	0.21	1.27	0.230	1.331
Elder-berry	13.8	0.459	0.211	0.111	0.039	0.33	1.36	0.258	1.196
Bilberry	25.8	0.381	0.146	0.093	0.040	0.54	1.31	0.290	1.019
Cowberry	25.8	0.425	0.169	0.193	0.076	0.48	1.04	0.476	1.027
Cranberry	21.9	0.402	0.107	0.626	0.187	2.70	1.15	1.351	0.880
Rowan berry	25.8	0.647	0.226	1.453	0.550	4.13	1.27	2.545	0.971
Moravica	25.8	0.456	0.201	0.714	0.300	5.01	1.73	1.704	1.088
Nero	11.8	0.553	0.244	0.451	0.223	1.51	1.35	0.817	0.921
Grape									
Müll. Turg.	29.9	0.337	0.114	0.128	0.025	0.50	1.42	0.832	1.623
Burgundy	29.9	0.357	0.121	0.172	0.027	0.65	1.48	1.036	1.693
Ryzlink R.	29.9	0.299	0.118	0.110	0.025	0.51	1.45	0.773	1.620

fruit. At the same time compression deformation x is used for calculation of the corresponding value for relative compression ε (Fig. 1b).

Figure 1c contains a typical shape of the berry-like fruits deformation curve in logarithmic scale. This curve has two linear parts, that can be defined by the following parameters: $a_1, n_1, a_2, n_2, \varepsilon_1, \alpha_1, \varepsilon_m, \alpha_m$. All these parameters have been determined for each deformation curve on the base of linear regression analysis of the obtained relations ln α - ln ε in two parts of the deformation curve.

RESULTS AND DISCUSSION

Table 2 contains the obtained values of parameters that determine the deformation curve in logarithmic scale. It shows the big variation in these parameters for different sorts of berry-like fruits, moreover the strong dependence of these parameters on maturity of the fruits. Change of shape of a deformation curve of currant variety Heinemann with change of its maturity is displayed in Fig. 2. The two characteristic values of α at strength limit α_m and at boundary point α_1 decrease in time. At the same conditions the variability of these values decreases, too. The decrease of α_m (α_1) for the base part of currant inflorescence is much lower than for its top part (Fig. 3). In case of top part of currant inflorescence the decrease of α_m during our observation of it makes about 80 % of the initial value.

Parameters ε_1 and ε_m for currant at first increase (in premature stage) and lately decrease (overmature stage), (Fig. 3). It seems

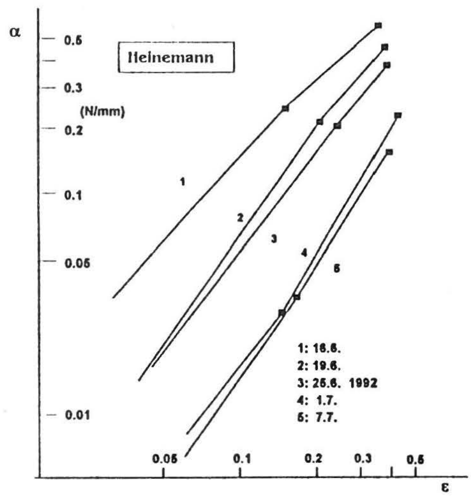

Fig. 2. Examples of compression curves in logarithmic coordinates in different stages of maturity.

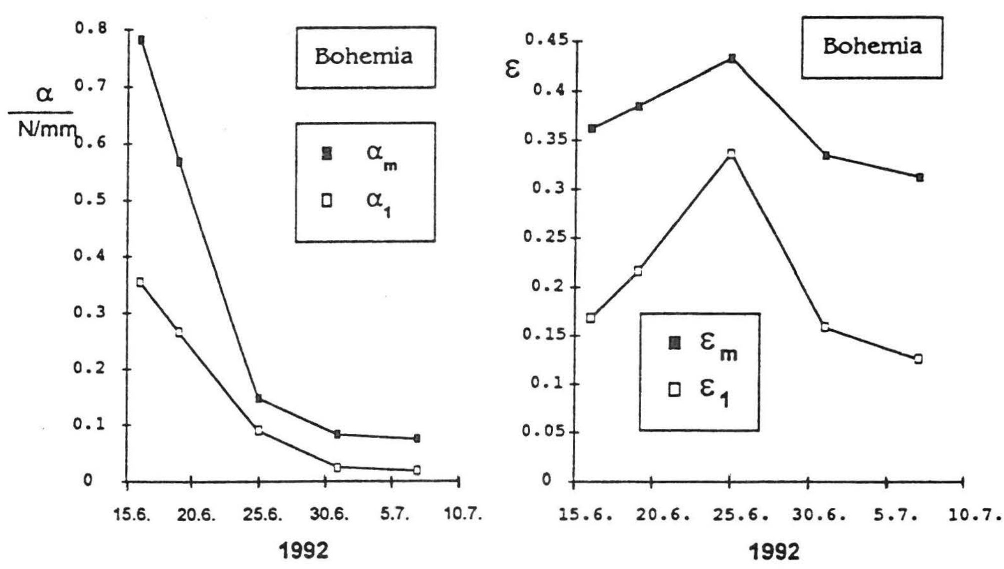

Fig. 3. Examples of changes of toughness (α) and/or chracteristic relative compressions (ε_m, ε_1 - see Fig. 1) that have been observed in time of ripening.

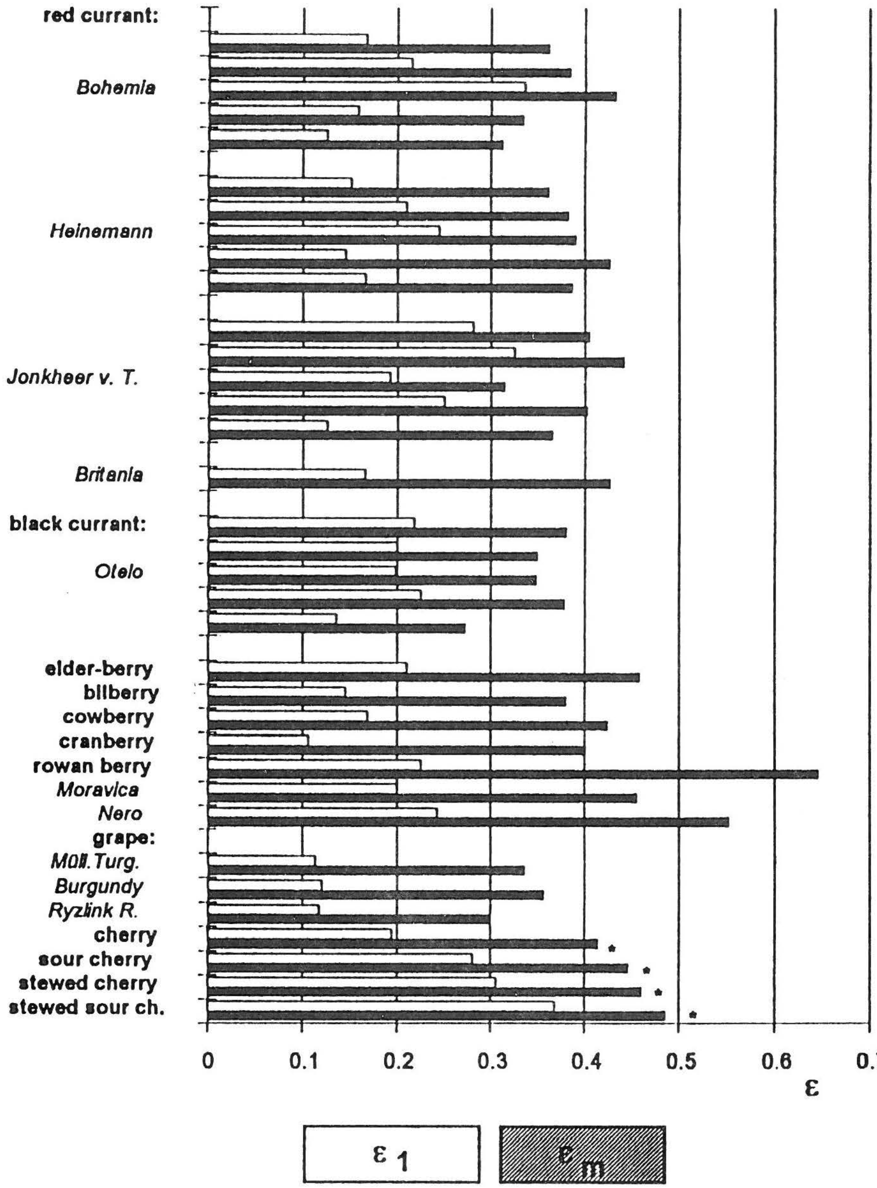

Fig. 4. Mean values of characteristic relative compressions (ε_m ,$\varepsilon_1$in Fig. 1) for different products. The values of ε_1 and ε_m for different varieties of currant that have been obtained in the whole ripening time (Table 2), [Blahovec, et. al. unpublished data for cherries].

that two-part shape of deformation curve is typical for all berry-like fruits to be studied, but the previous studies of cherries (Fig. 4) show that the second part of deformation curve cannot be described by the power relation between the compression force and relative compression. The value of ε_1 is in the range 0.1-0.23 for our experiments. Cracking of the fruit skins appears usually at relative compression 0.35-0.47. Much less

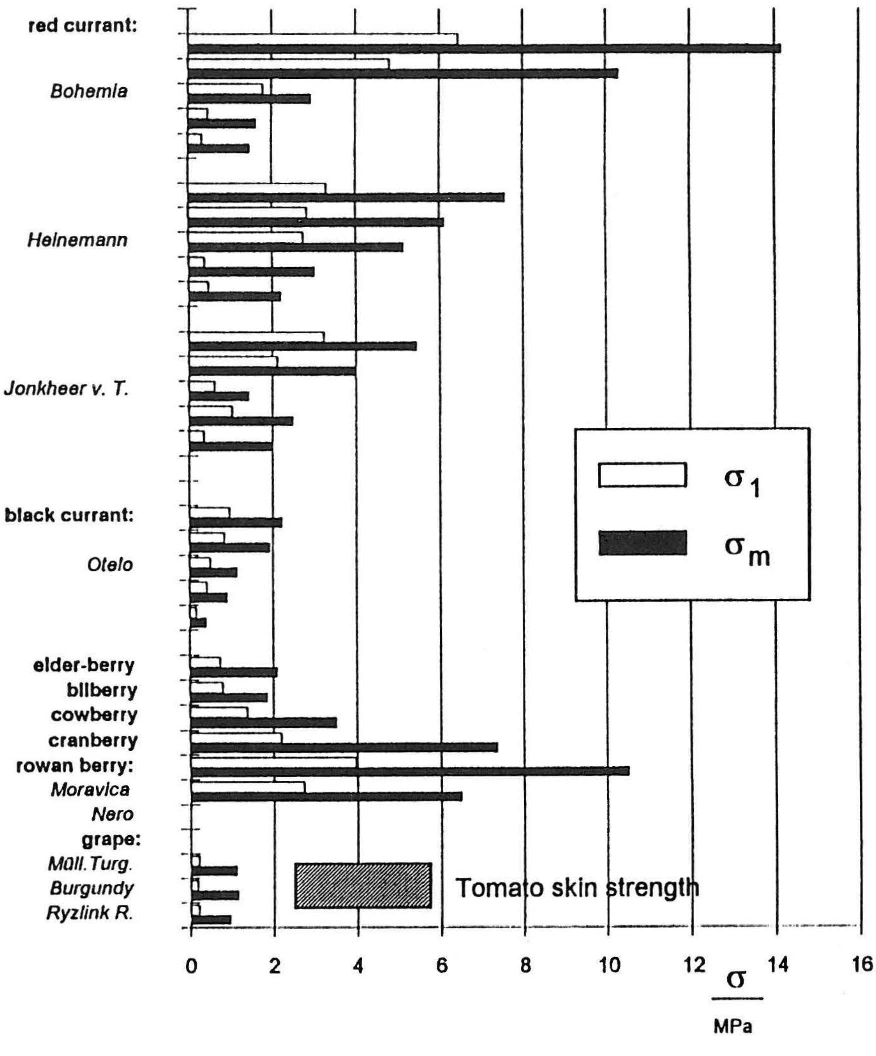

Fig. 5. The strength of the berry skin for different tested products - the tomato skin strength [2].

frequent are some lower values (overmatured fruits) and may be even then higher values (canned fruits and some special sorts of fruits).

Exponents n_1 and n_2 behave in time in very similar manner as the discussed parameters ε_1 and ε_m. At the beginning they increase and when all the inflorescence achieves the full maturity their values decrease. The initial value of the exponent n_2 is usually lower then the initial value of exponent n_1 this inequality is changed during the ripening of the fruit, and the opposite inequality can be observed in mature and overmature stage of the currant fruits.

The influence of ripening process on deformation behaviour of currant fruits is a prototype of changes that can be expected also for other berry-like fruits. During the ripening of berry-like fruits the berry skin thickness decreases and the skin behaves more similarly as a membrane and this is why exponents n_1 and n_2 increase and parameters

a_1 and a_2 decrease. At the same conditions the stresses α_1 and α_2 must decrease. In overripening period the values of all characteristic parameters depend only on the properties of fruit skin.

The strength of the berry skin strongly depends on its state of ripening (Fig. 5 - ripening of currant). For example for variety Bohemia the strength of the fruit skin decreases from the initial value more than 10 MPa to the final value less then 2 MPa and the similar relations can be observed for the other tested varieties. Similar depression during currant fruit ripening can be observed also for the boundary stress α_1. The obtained values for strength of berry-like fruit skins are very similar to the values of skin strength that have been obtained directly by tension test (for example for tomato - Fig. 5).

CONCLUSIONS

It was found that two-plate compression behaviours of different berry-like fruits are very similar and all the process can be divided into two parts. The first of them, i.e., the initial part can be well described by the power relation between force and relative compression. In most cases a relation of this type (power relation) can be also used for a description of the second part with higher forces and deformations, the part typical by the final skin rupture. The boundary between these parts appears usually at relative compression 0.1-0.23 and ruptures of the fruits are observed at relative compression 0.35-0.58. During ripening process the berry-like fruits become softer and at the same time the strength of them decreases about 90 %. The strength of the fruit skin was observed in range 0.5-5 MPa in good agreement with some previous directly measured values of tomato skin strength.

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