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Textural properties of sweet pepper depending on genotype and method of cultivation

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The experiment was carried out in the period 2018-2020 on the territory of the seed company "Superior D.R" in Velika Plana, Republic of Serbia, with six varieties of sweet pepper grown under greenhouse and open field conditions. The effect of genotype and method of cultivation on mechanical properties related to the textural characteristics was evaluated. The laboratory tests were conducted by the TA.XT Plus texture analyzer. The obtained force-deformation curves were analyzed for yield force, rupture force, modulus of flesh elasticity and deformation work. The cellulose content was also measured, but no significant correlations with the textural parameters of the fruits were found. The results of two-way analysis of variance indicated that the growing mode had an impact on modulus of flesh elasticity (29.73%), rupture force (11.09%) and yield force (10.68%). A significant influence of the genotype was recorded on the dynamic of rupture force (47.43%), modulus of flesh elasticity (25.60%) and deformation work (33.82%). Established genetic determination combined with an appropriate method of cultivation will be a good basis for successful breeding aimed at improving of the textural characteristics of pepper.

Keywords: *Capsicum annuum* L., yield force, rupture force, elasticity, deformation work, field, greenhouse

INTRODUCTION

Sweet pepper is a traditionally preferred vegetable in Serbia. The numerous specifics and the excellent adaptation to the local ecological conditions make the country very advantageous for growing pepper as this culture adapts perfectly to its climatic conditions and ecological factors [1].

Pepper fruits display high antioxidant activity determined by gallic acid equivalents. Many compounds are potential contributors to the total antioxidant capacity including ascorbate, flavonoids, carotenoids, phenolics and capsaicinoids [2]. Among the four maturity stages (immature green, green, immature red and red), the red one possesses enhanced functional properties [3]. Pepper is consumed both fresh and processed. Freshly chopped pepper must have an attractive appearance, an acceptable aroma, a suitable texture and a positive nutritional appearance to motivate initial and continuous purchases by consumers [4]. According to Beaulieu *et al.* [5] consumers often buy the first time based on appearance but repeated purchases are guided by expected quality factors determined by aromatic compounds and texture. Food texture can be evaluated by sensory analysis and by physical and mechanical properties of the foods. The second method is more consistent and is generally free from human factors [6].

Texture is the result of complex interactions between nutrients at the microstructure level and at higher structural levels such as tissue structure (cellular orientation, porosity) and the different types of tissues or organs that make up the nutrients [7]. Crispy textures are especially important in vegetables as consumers associate them with freshness and health [8]. Crispness is more suitable for wet vegetables consisting of living plant cells [9]. Both the cell wall strength of pepper fruits and the turgor pressure of pepper are related to characteristics such as hardness, fragility and crunching. These living cells have the property of turgor and intracellular pressure acting out against the cell wall which is balanced by another in force imparted by the hardness and elasticity of the cell wall [10]. According to Bourne [11] the textural properties of pepper are a group of physical characteristics affecting the structural elements of food and are felt when touched. They are also associated with the deformation and disruption of the structure of food under the action of force. They can give an objective assessment of the behavior of the pepper fruits after thermal, chemical or mechanical treatment [12].

During the warm months of the year pepper in the Republic of Serbia is grown both in polyethylene greenhouses and outdoor [13]. Decreased fruiting in pepper is common when daily temperatures are over

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32°C [14]. Excessive temperatures lead to quality losses, e.g., alterations in form, color and texture of pepper fruits [15]. By reduced light intensity, the height of the plant, the number of nodes and the size of the leaves increase. In traditional areas pepper production in greenhouses is expanding to prevent yield reductions [16].

The aim of the present study was to evaluate the effect of genotype and method of cultivation on mechanical properties related to the textural characteristics of sweet pepper *Capsicum annuum* L.

EXPERIMENTAL

Method of cultivation

The experiment was conducted in the period 2018-2020 on the territory of the seed company "Superior D.O.O" in Velika Plana, the Republic of Serbia. Two variants of cultivation were applied: in plastic greenhouses and outdoor in five replicates. The seedlings were transplanted into greenhouses in the first ten days of May and into an open field in the second ten days of the same month. Standard agronomic practices such as fertilization and plant protection were used during the cultivation period. The plants were harvested at botanical maturity in early August from the greenhouse and in late August from the field.

Plant material

Six sweet pepper cultivars of *kapia* type were grown in the experiment. Four of them were Serbian (Slonovo uvo, Prizrenka, Belo uvo, Emina) and one (Ivailovska kapia) originated from Bulgaria. Italian variety Corno di Toro Rosso with horn-shaped fruits was also included in the study due to its widespread use in the production of ajvar in the Republic of Serbia.

Physical and chemical analyses

Textural parameters were studied one day after harvesting. The fruits for analyses were selected on the base of minimum variation in shape, color, size and firmness. They were cut longitudinally into strips of constant length. The laboratory tests were conducted by the TA.XT Plus texture analyser (Stable Micro Systems, UK) equipped with a heavy duty platform (HDP/90) with holed plate and a 2 mm diameter stainless steel puncture probe (SMS P/2) (Fig. 1). The instrument was set at a test speed of 2 $mm.s^{-1}$ and a travel distance of 10 mm. The analysis was performed on 5 individual fruits of each cultivar and method of cultivation. The measurement was done in the middle part of the longitudinal slices with skin. The force-deformation curves were analyzed for yield force (1st force maximum), modulus of flesh elasticity (slope up to 2nd maximum), deformation work (area under the curve up to 2nd maximum) and rupture force (force maximum) (Fig. 2).

Fig. 1. TA.XT texture analyzer

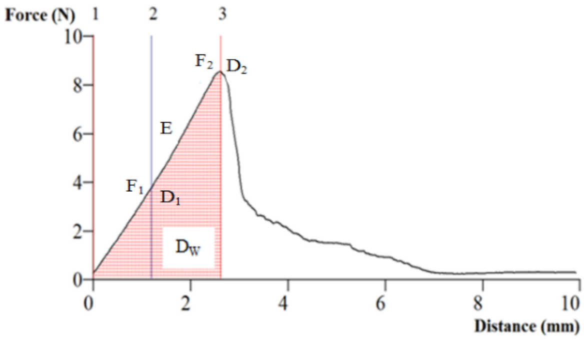


Fig. 2. Typical force-distance curve of the fresh pepper tissue. F_1 - Yield force [N]]; D_1 -Yield deformation [mm]; F_2 - Rupture force (firmness) [N]; D_2 - Rupture deformation [mm]; Y - Modulus of flesh elasticity [$N.mm^{-1}$] = F_2 / (D_2-D); Dw - Deformation work [N.mm] = $\int_{D_0}^{D_2} F \cdot D_D$.

The cellulose content was measured on the same five fresh whole pepper fruits from each variant using Henneberg-Stohman method [17].

Data analyses

Significant differences in the studied characters of pepper genotypes were determined by Duncan's multiple range test ($P<0.05$). A two-way analysis of variance was applied to evaluate the effect of genotype, method of cultivation and their interaction on the analyzed traits. Pearson correlation coefficients were estimated in order to examine the relationships between the studied parameters. Coefficient of variability (CV) and standard deviation (sd) were also calculated. All data analyses were performed using the SPSS-16 software.

RESULTS AND DISCUSSION

The obtained force-distance curves of fresh pepper tissue had a specific design for each of the genotypes (Fig. 3).

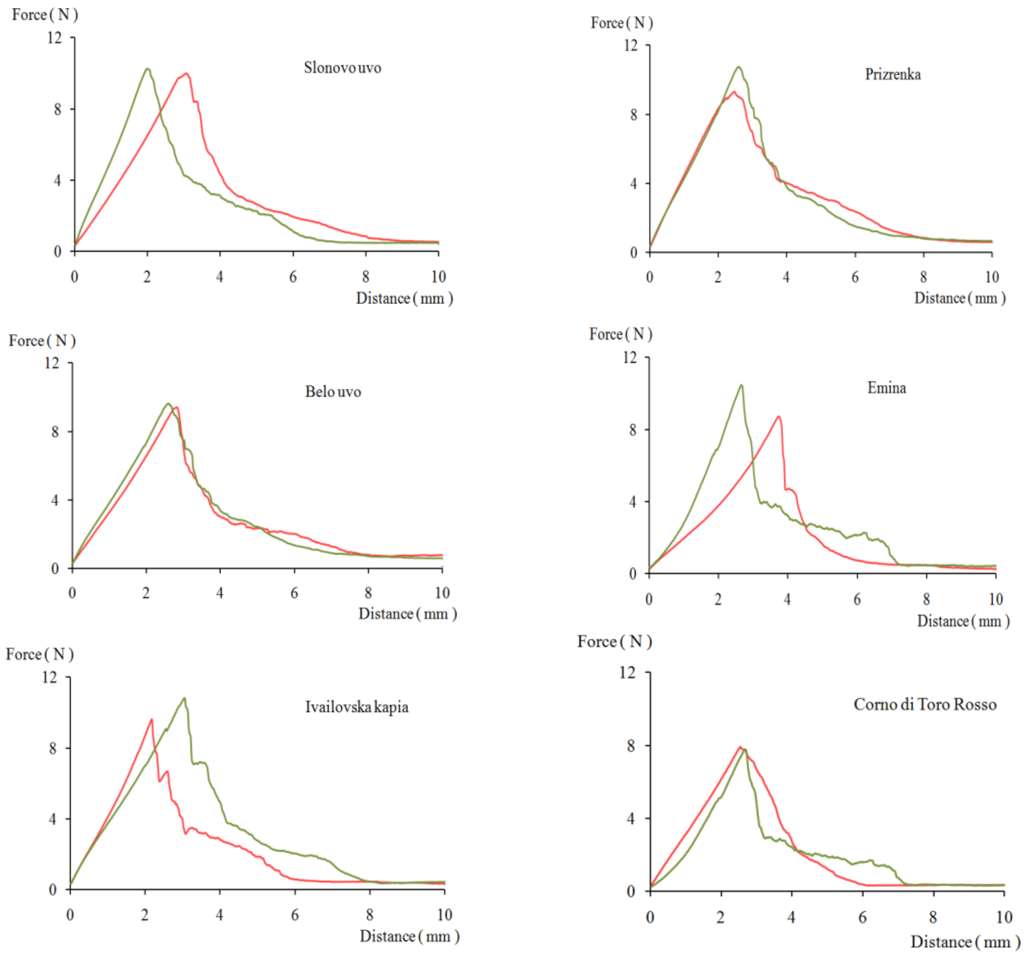


Fig. 3. Force-distance curves of fresh pepper tissue obtained from field (−) and greenhouse fruits (−)

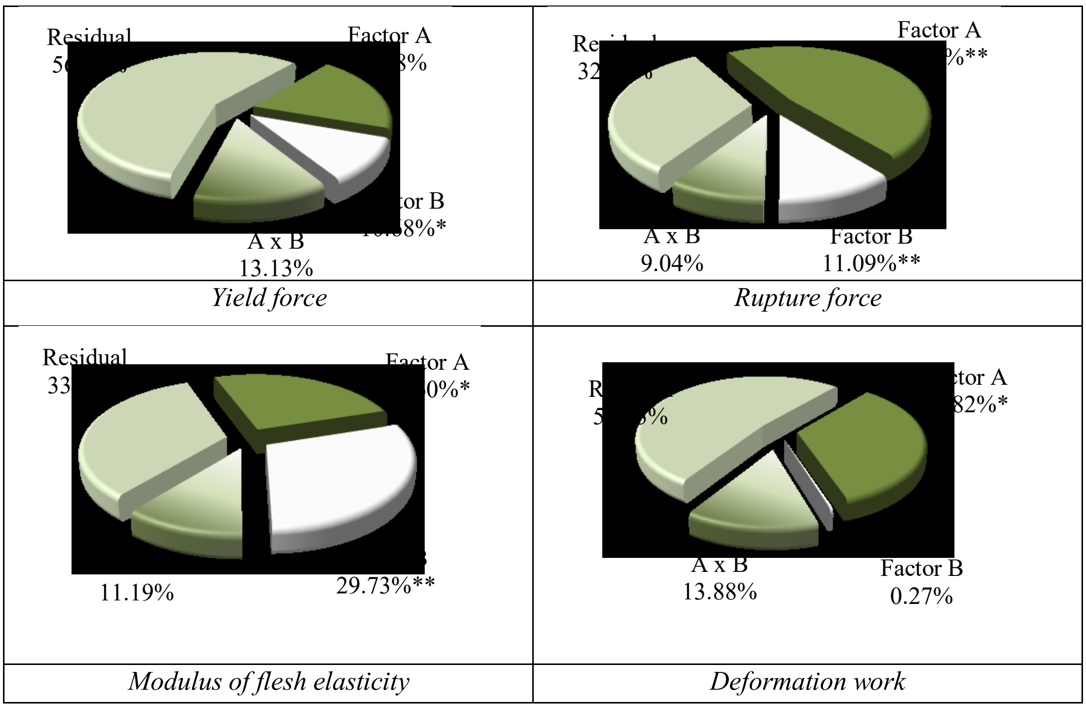


Fig. 4. Effect of genotype (factor A) and method of cultivation (factor B) on the studied mechanical parameters in pepper

Most of the investigated pepper varieties grown under field conditions were characterized by a lower curve maximum compared to those grown in the greenhouse. Belo uvo and Corno di Toro Rosso had close positions of the maximum peak and very similar type of the curves describing both cultivation methods. The initial slope of the force-distance curves for Slonovo uvo and Emina as field production were much less steep than the curves defining greenhouse production.

Genotypic differences with respect to yield force were better expressed in pepper fruits from the field (Table 1). Variety Emina had the lowest value compared to the other varieties. The fruits of the pepper varieties grown in the greenhouse did not differ significantly in the studied mechanical parameter. Low CV levels for both variants were observed.

Higher values of rupture force with the exception of Corno di Toro Rosso were recorded in the varieties grown under greenhouse conditions indicating higher resistance to mechanical damage of pepper tissue. The studied textural parameter was also genetically determined. Statistical differences were proved between the variety of horn-shaped fruits and the group of five *kapia* type varieties in the greenhouse and four ones in the field. As a whole, the investigated varieties of *kapia* type formed harder fruits in greenhouse plants.

Modulus of flesh elasticity shows how easily a specimen can be deformed. All genotypes grown under greenhouse conditions were characterized by higher modulus of flesh elasticity values than those grown under field conditions. This means that their fruits were stiffer and more resistible to plastic deformation. A genetic expression was observed in both cultivation methods. The lowest values of the modulus of flesh elasticity were recorded in Emina from the field and in Corno di Toro Rosso from the greenhouse. Relatively low CV values (below 11%) characterized the variation between varieties as slight. Deformation work was the most variable inter-variety parameter with CV over 11 percent regardless of the cultivation method. Italian variety Corno di Toro Rosso seemed to absorb less energy for the deformation before fracture of the fruit tissue than the *kapia* type varieties. The most difficult to deform were the pepper fruits of Slonovo uvo, Prizrenka and Emina from the field and fruits of Prizrenka and Ivailovska kapia from the greenhouse.

The information obtained about the pepper texture profile revealed lower values of the coefficient of variability in the investigated mechanical parameters for the field variant. It was better expressed in terms of deformation work.

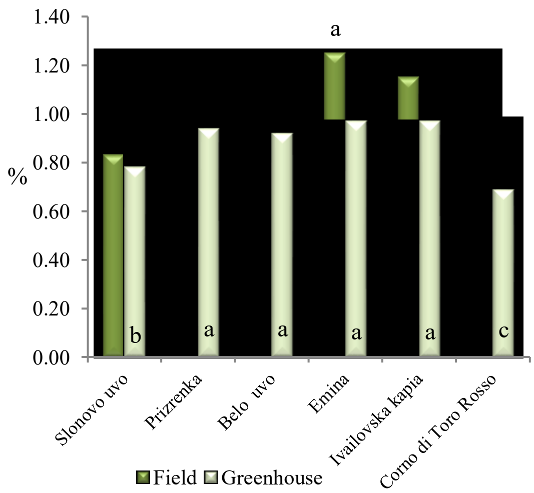
Higher influence by the genotype than by the method of cultivation was recorded on the dynamics of the deformation work and the rupture force (Fig. 4).

A significant very close impact of the genotype (25.60%) and the method of cultivation (29.73%) on the modulus of flesh elasticity was established. The growing mode did not impact on the deformation work. The influence of the interaction between both factors on the studied mechanical parameters was insignificant.

Generally, the results of two-way analysis of variance indicated that the method of cultivation could change the elasticity and the firmness of the pepper fruits. The comparatively high values of the residual factor could be explained by the influence of other factors on the texture parameters such as turgor cell pressure, pectin in cell wall, lamella, etc., that were not a subject of this study.

The mechanical parameters of fruits and vegetables depend on the cell arrangement in the tissue, especially on cell dimension and cell wall structure. Some part of this variation can be expressed by crude fiber content [18]. Tissue firmness has its source in the cell walls and their carbohydrate cellulose, hemi-cellulose including pectic substances [19]. It is presented as the major fiber constituent in most of the foods [20]. Cellulose gives plants the necessary strength and elasticity. This was the main reason to analyze the content of cellulose in the pepper fruits and to search for a relationship with the textural parameters in the studied pepper varieties.

Genotypic reaction regarding the cellulose content in pepper fruits was observed in both methods of cultivation (Fig. 5).



a,b… Duncan's multiple range test (P<0.05)

Fig. 5. Cellulose content of pepper fruits grown under field and greenhouse conditions

It was better expressed in pepper fruits from the greenhouse. Varieties Emina and Ivailovska kapia had the highest values of cellulose regardless of the growing procedure. However, these varieties did not display the highest values of the studied mechanical parameters (Table 1). The correlation coefficients showing the relationship between the cellulose content and the textural parameters in the field fruits were not significant (Table 2). A moderate correlation was proved for the modulus of flesh elasticity and rupture force in the greenhouse variant. The lack of significant correlations between the cellulose content and the measured texture parameters could be explained by the structure of the pepper fruits. According to Mohsenin [6] the test specimen should ideally be isotropic and homogeneous**.** In reality, all plant food materials are cellular composite structures formed by the accumulation of fibers and are therefore inherently inhomogeneous and anisotropic [21]. Another probable reason in the experiment may be due to the difference in the parts of the pepper fruits that were involved in the measurement. The mechanical parameters were determined in the middle area of the longitudinal slices. In contrast, the cellulose content was analyzed after a fairly good homogenization of the whole pepper fruit material.

Table 1. Textural parameters of the studied pepper cultivars

Cultivar	Yield force (N)	Rupture force (N)	Modulus of flesh elasticity (N.mm^{-1})	Deformation work (N.mm)
Field				
Slonovo uvo	4.275^{a}	9.995^{a}	4.682^{ab}	13.527^{a}
Prizrenka	4.085^{a}	9.328^{a}	4.403^{ab}	12.717^{a}
Belo uvo	4.281^{a}	9.419^{a}	4.752^{ab}	11.532^{ab}
Emina	3.501^{b}	8.718^{ab}	3.813^{b}	12.667^{a}
Ivailovska kapia	4.126^{a}	9.631^{a}	4.919^{a}	11.542^{ab}
Corno di Toro Rosso	3.998^{a}	7.918^{b}	4.040^{ab}	9.536^{b}
Mean ($\bar{x} \pm$ sd)	4.044 ± 0.288	9.168 ± 0.742	4.435 ± 0.433	11.920 ± 1.397
CV (%)	7.12	8.09	9.77	11.72
Greenhouse				
Slonovo uvo	4.123^{ns}	10.260^{a}	5.550^{a}	11.087^{ab}
Prizrenka	4.243^{ns}	10.762^{a}	5.401^{a}	13.268^{a}
Belo uvo	4.694^{ns}	9.624^{a}	5.310^{a}	10.414^{ab}
Emina	4.300^{ns}	10.468^{a}	5.429^{a}	11.954^{ab}
Ivailovska kapia	4.850^{ns}	10.825^{a}	5.266^{a}	13.817^{a}
Corno di Toro Rosso	3.939^{ns}	7.775^{b}	4.049^{b}	8.848^{b}
Mean ($\bar{x} \pm$ sd)	4.358 ± 0.347	9.952 ± 1.151	5.168 ± 0.557	11.565 ± 1.847
CV (%)	7.96	11.57	10.77	15.97

^{a,b}… Duncan's multiple range test (P<0.05); ^{ns} - not significant

Table 2. Correlation analysis of the studied pepper properties

	C (F)	C(G)	YF (F)	YF (G)	DW (F)	DW (G)	MFE(F)	MFE (G)	RF (F)	RF (G)
C (F)	♦									
C(G)	0.276	♦								
YF (F)	-0.447	-0.152	♦							
YF (G)	0.087	0.249	0.403	♦						
DW (F)	0.157	-0.307	0.185	0.245	♦					
DW (G)	0.097	-0.036	0.214	0.544^{*}	0.819^{**}	♦				
YM (F)	-0.199	0.460	-0.218	-0.224	-0.865^{**}	-0.715^{**}	♦			
YM (G)	-0.051	0.551^{*}	-0.384	-0.317	-0.779^{**}	-0.700^{**}	0.948^{**}	♦		
RF (F)	-0.212	0.432	0.129	-0.016	-0.097	-0.075	0.543^{*}	0.553^{*}	♦	
RF (G)	0.065	0.540^{*}	-0.157	0.401	0.296	0.559^{*}	0.045	0.148	0.525^{*}	♦

C - cellulose; YF - yield force; DW – deformation work; MFE–modulus of flesh elasticity; RF – rupture force; F - field; G - greenhouse

Simple correlations between the studied textural parameters were evaluated (Table 2).

A very strong positive correlation (r = 0.948) was found between the moduli of flesh elasticity recorded in field and greenhouse fruits. A strong positive correlation (r = 0.819) was established between deformation work measured in the field fruits and in the greenhouse ones. The high values of these coefficients of correlation show that the above-mentioned textural parameters were changed regularly in both studied methods of cultivation.

Negative strong correlations were recorded between modulus of flesh elasticity and the deformation work regardless of the cultivation method. The other correlations ranged from weak to moderate and did not actually have any practical application. Hence, none of the studied mechanical parameters can be used as a primary indicator for determining the quality of the texture of the pepper fruits.

CONCLUSION

In the present experiment, it was established that the method of cultivation could change some of the investigated mechanical parameters. Positive effects of greenhouse crop growing were observed in modulus of flesh elasticity and rupture force. Pepper fruits of *kapia* type were harder, stiffer and more resistible to plastic deformation than the ones grown under field conditions. The studied parameters were also genetically determined, which is a good basis for successful breeding aimed at the improving the textural characteristics of pepper.

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