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Relation between the bean pod shape factor and the force required for pod opening

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A b s t r a c t. The paper discusses the research on the relationship between the bean pod shape (defined by the shape factor), its moisture content, and the force necessary for opening it. The research was performed on five cultivars of beans grown for dry seeds - at five moisture content levels. For each tested option the width and thickness of 100 pods was measured in a cross section perpendicular to the main axis of the fruit, passing through its middle part. The shape factor was determined as the ratio of pod width to thickness. As a result of the research, an increase in the shape factor and the force needed for pod opening with rising pod moisture content was recorded for all bean cultivars. This means that internal stresses in sclerenchyma, which increase with pod drying, tend to open the pod and increase its convexity. The more convex the pod, the less force is required for its opening.

K e y w o r d s: bean pod, shape factor, susceptibility to cracking

INTRODUCTION

An important problem in the cultivation of leguminous plants is, among others, the tendency of pods to burst and strew seeds, both before and during harvest, leading to considerable seed losses [5]. The susceptibility of pods to bursting is conditioned by their anatomic-morphological structure [2,3]. The main characteristic causing pod bursting is the structure of the endocarp cell wall, which consists of fiber layers with strongly thickened sclerenchymatic cells obliquely arranged to the fruit axis. As a result of various micro-fibril arrangements in cell walls, these layers of thick-walled parchment stratum shrink in various directions during drying and this causes pod cracking along the ‘abdominal’ seam (at carpel fusion) and dorsal seam (the main vain/rib).

Other significant factors determining the pod strength are its moisture content [1,4] and shape [7,8]. This paper presents the research on the relationship between the shape of a bean pod (defined by the shape factor), its moisture content, and the value of pod opening force.

MATERIAL AND METHODS

The research was performed on pods of five cultivars of beans grown for dry seeds, at five moisture content levels (Table 1). In order to obtain suitable moisture contents of pod samples they were moistened in a foil tunnel to a

T a b l e 1. Average moisture content (%) of pods of studied bean cultivars

Cultivar	Moisture content level				
	I	II	III	IV	V
Aura	11.0	14.0	18.1	20.0	26.8
Bor	10.2	14.2	17.7	21.5	25.1
Igołomska	12.2	13.9	17.3	20.3	26.7
Nida	11.7	14.0	17.9	21.9	25.0
Prosna	12.5	14.9	17.7	20.9	26.1
Average	11.5	14.2	17.7	20.9	25.9

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moisture level of about 28-30 %, and then dried at approx. 20°C to reach the required value.

For each tested option the width and thickness of 100 pods was measured in a cross section perpendicular to the main axis of the fruit, passing through its middle part. The shape factor s_f was determined as the ratio of pod width to thickness:

$$s_f = \frac{d}{e} \qquad (2)$$

s_f – shape factor, d – pod width (mm), e – pod thickness (mm).

The susceptibility of pods to bursting was determined by means of a pressure method consisting of the introduction of compressed air in order to cause pod bursting [4,6].

RESULTS AND DISCUSSION

As a result of the research, an increase in the shape factor with a rising moisture content of pods was recorded for all bean cultivars (Table 2, Fig. 1). It may mean that internal stresses in sclerenchyma, which increase with pod drying, tend to open the pod and increase the convexity of the shells of those fruits, and the more convex the pod the less force is required for its opening.

The pods of the Aura, Nida and Prosna cultivars had the highest shape factors (Table 2), and those of Igołomska and Bor had the lowest shape factors. For the first two moisture-content levels, all tested cultivars differed significantly statistically in respect to their shape factor. At the third level no significant difference existed between the Prosna and Nida cultivars or, as the moisture content increased further, between the Prosna, Nida and Aura cultivars.

The analysis of pod shape factor increase with a rising moisture content found that it was the highest for the Prosna and Nida cultivars. This rise of this pod shape factor was not statistically significant only for the Prosna cultivar at the second moisture content level, but also for Nida at the third moisture content level.

T a b l e 2. Average values of pod shape factor s_f of studied bean cultivars versus their moisture contents

Cultivar	Moisture content level					Average A	$LSD_{0.05}$
	I	II	III	IV	V		
Aura	1.256	1.331	1.350	1.366	1.365	1.334	0.0416
Bor	0.988	1.100	1.108	1.122	1.139	1.092	0.0343
Igołomska	0.942	1.007	1.038	1.045	1.086	1.024	0.0342
Nida	1.199	1.249	1.272	1.335	1.400	1.291	0.0433
Prosna	1.152	1.181	1.246	1.357	1.422	1.272	0.0545
Average B	1.107	1.174	1.203	1.245	1.282	1.202	0.0239
$LSD_{0.05}$	0.0393	0.0420	0.0412	0.0442	0.0375	0.0199	

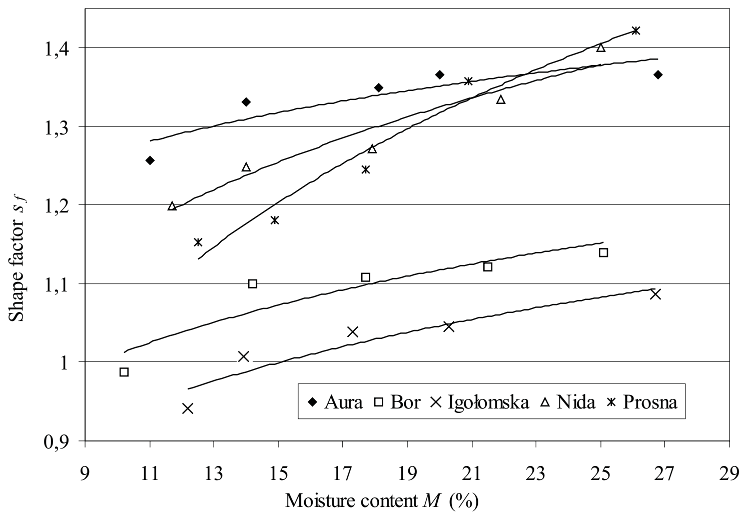

Fig. 1. Bean pod shape factor (s_f) versus pod moisture content (M).

Conversely, the smallest pod shape changes occurred for the Aura cultivar, for which the statistically significant increase in shape factor occurred only at the second moisture content level.

The dependence of the pod shape factor of tested bean cultivars on their moisture content is well described by the logarithmic function (in Fig. 1), in the form of:

$$s_f = a\, ln(M) + b \tag{2}$$

where: s_f – shape factor, M – pod moisture content (%), *a, b* – equation coefficients.

The coefficients for above equations are specified in Table 3.

The reduction in the shape factor, recorded for studied cultivars as they were drying, meant that internal stresses in fiber layer, which increase with pod drying, tend to open it and increase its convexity. It confirms the conclusion of Szwed *et al*. [7,8] that the opening of more convex pods requires smaller force, because smaller curve radii increase the arm of the pod shell bending moment in the perpendicular plane to the direction of the parchment layer fibers.

The dependence of the specific pod bursting force of the studied bean cultivars on their shape coefficient is defined by the linear function (Fig. 2), in form of:

$$F_s = a\, s_f + b \tag{3}$$

where: F_s - specific pod-bursting force (Nmm^{-1}), s_f - shape factor, *a, b* - coefficients of the equation.

Coefficients of equations describing this relationship are specified in Table 4.

The results presented in Fig. 2 show that the highest effect of the pod shape factor on the value of force necessary for pod opening occurred in the Igo^{3}omska cultivar, and the smallest for Prosna (a shape factor rise by 0.1 caused the bursting force to rise by 0.25763 Nmm^{-1} and 0.04862 Nmm^{-1}, respectively).

The analysis of the results, presented in Figs 1 and 2, leads to the conclusion that the Bor and Igołomska cultivars, which have most convex pods (of a lower shape factor) also showed a higher resistance to cracking. The pods of the Nida and Prosna cultivars were the most flat and were the easiest to open. This means that the difference in pod susceptibility to cracking is determined to a higher extent by factors other than their shape.

T a b l e 3. Values of coefficients of equation $s_f = a\, ln(M) + b$, describing dependence of pod shape factor s_f on pod moisture contents M

Cultivar	a	b	R^2
Aura	0.1182	0.9975	0.7783
Bor	0.1548	0.6536	0.8442
Igołomska	0.1633	0.5573	0.8897
Nida	0.2430	0.5965	0.9432
Prosna	0.3947	0.1346	0.9653

T a b l e 4. Values of coefficients of equation $F_s = a\, s_f + b$ describing dependence of specific bursting force F_s on pod shape factor s_f

Cultivar	a	b	R^2
Aura	1.9144	-2.0626	0.7114
Bor	1.4441	-1.0381	0.6254
Igołomska	2.5763	-2.1001	0.7456
Nida	1.7580	-1.8577	0.9381
Prosna	0.4862	-0.2938	0.9235

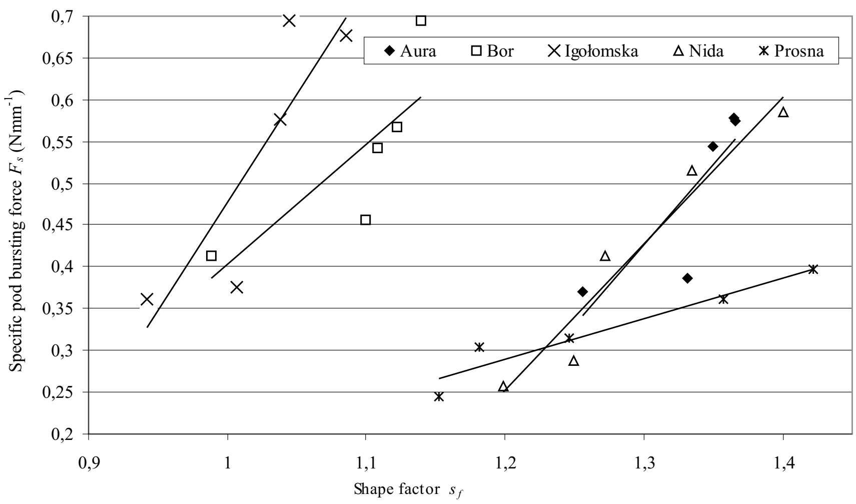

Fig. 2. Specific pod bursting force (F_s) of studied bean cultivars versus their pod shape factor (s_f).

CONCLUSIONS

1. Rising moisture content of bean pods caused an increase of the shape factor for all studied varieties, which means that internal stresses in sclerenchyma, rising as the pods dry, tend to open them and increase the convexity of bean pod shells. On the other hand, the more convex the pod the smaller bursting force is required for its opening.

2. The highest effect of pod shape factor variation on the value of force required for pod opening was discovered for the Igołomska cultivar, and the lowest effect for the Prosna cultivar.

3. Bean cultivars with more flat pods (higher shape coefficient) were more susceptible to cracking. This means that crack-susceptibility variation is determined by factors other than the pod shape alone.

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