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Energy of bean pod opening and strength properties of selected elements of their structure

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Summary. The study presents the correlations of bean pod opening energy in the varieties Narew, Nida, Warta and Wawelska with their geometric features and strength properties of selected elements of their structure. It has been confirmed that the pods which are more susceptible to cracking are those with a flatter section (wider and thinner), lower thickness of fibre and parenchyma layers as well as lower ration of the thickness of parenchyma and the fibre layer undergoing less deformations and more resistant to tearing, whose sclerenchymatous connections of the dorsal seam are more resistant to tearing and the abdominal seam are less resistant.

Key words: bean pod, elements of construction, strength properties, energy of pod opening.

INTRODUCTION

One of the unfavourable features of legumes is their susceptibility to cracking their pods and seeds falling out before and after harvesting [6, 12, 18, 19].

Susceptibility of pods to cracking is a variety feature and is conditioned by their anatomic and morphological structure. The main feature allowing the breaking of the pod is the structure of its endocarpium in which there is a layer of fibres constructed from strongly thickened sclerenchymatous cells located diagonally to the axis of the fruit. As a result of various location of micro fibrils in cellular walls, during drying they shrink in various directions and there is the breaking of the pod along with the ventral and dorsal suture. The most significant of the elements of the internal structure of the pods are the content and structure of the fibre in vascular bundles and walls of their shells. [3, 5, 9, 11, 24].

The susceptibility to cracking is also conditioned by their shape in the layer of the transverse section [10, 21].

The aim of the work was to determine the geometric features and strength properties of selected elements of the structure of the pod and comparing them with the susceptibility to cracking of these fruits whose opening energy is measured and determined by the pressure method.

MATERIAL AND METHODS

The research was carried out in 2008-2010. Bean was cultivated in the experimental field of the Department of Engineering in Agricultural Food Production in Rzeszów. The research was conducted on pods of bean cultivated on dry seeds of the varieties: Narew, Nida, Warta and Wawelska, which were characterized by varied seed and pod sizes (Tab. 1).

Pod dimensions were calculated using an electronic slide calliper with the accuracy of 0.01 mm. Length was measured from the beginning of stalk to the peak, and width and thickness in cutting plane of perpendicular to main axis of the fruit, leading through its centre. Thickness and width of the fibre layer and seam bundles were measured using an electronic dial gauge with the accuracy of 0.001 mm. Surface of cross section of the analyzed pod structure elements was calculated as a product of width and thickness.

The shape factor, s_f, was determined as the ratio of pod width to its thickness:

$$s_f = \frac{d}{e}, \qquad (1)$$

where:

s_f – shape factor,
d – pod width [mm],
e – pod thickness [mm].

Strength research covers such pod structure elements as:

– fibre layer,
– seam sclerenchyma bundles; abdominal and dorsal

The research was conducted with the use of the testing machine ZWICK with which for the above mentioned pod the following structure elements were determined: critical stress, modulus of elasticity (Young's modulus) and deformation [2, 4, 7, 8, 22]. In order to separate fibre layer and seam sclerenchyma bundles from the other tissues, bundles were placed for 15 minutes in boiling water. Parenchyma tissues macerated in this way were removed (scraped off) with a blunt side of a scalpel so as to not damage sclerenchyma [11]. For the purpose of resistance tests ca 2 mm straps were cut from a fibre layer parallel to the direction of fibre location.

Energy required to open a pod was calculated with the pressure method which is based on bursting a pod by compressed air [15, 21]. Air volume in a pod was determined with modified pictometric method [13, 14].

Measurements were conducted on 80 pods for each of the tested varieties with their humidity within the range of 12.4-13.8%.

The result was statistically analyzed with Statistica 9 program, with which the variance analysis and LSD significance test were carried out [1].

RESULTS

The least susceptible to cracking (Fig.1) were pods of the Narew variety, which needed the energy of opening amounting to 258.1 mJ, on average. The greatest susceptibility occurred in the pods of Nida variety, which opened at the energy of 125,1 mJ, on average. The performed test LSD indicated that due to the average values of pod opening energy, all the tested bean varieties were significantly statistically different.

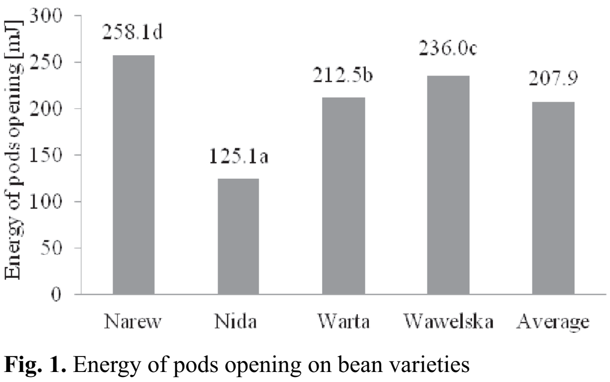

Fig. 1. Energy of pods opening on bean varieties
*different letters signify significant differences for the significance level α = 0.05

The pods of Wawelska variety (Tab.1) were statistically significantly the longest (118.6mm), Nida the widest (10.4mm) and with the greatest shape factor (1.28) and Narew the thickest (8.9mm). The shortest pods (96.8mm) were the Nida and the narrowest (9.7mm) and the thinnest (7.9 mm) were the Warta. The lowest shape factor (1.14) was found for the Narew variety.

Table 1. Geometric characteristics of bean pods and their correlation coefficient with pods opening energy

Specification	Dimension of pods [mm]			Shape factor of pod
	Length	Width	Thickness	
Narew	101.7b	10.2b	8.9b	1.14a
Nida	96.8a	10.4b	8.1a	1.28d
Warta	113.2c	9.7a	7.9a	1.24c
Wawelska	118.6d	10.2b	8.6b	1.19b
Correlation coefficients with energy of opening the pods	0.5335	-0.3302	0.6505	-0.9256

* different letters in column signify significant differences, as per LSD test (significance level of α = 0.05)

The energy of bean pod opening was highly and positively correlated with the length (0.5335) and thickness (0.6505) of pods and negatively, on average, with their width (-0.3302) and almost fully with the shape index (-0.9256). It means that the bean varieties whose pods are longer, narrower, thicker and with a less flat transverse section are more resistant to breaking. This regularity is confirmed in the conclusions of Szwed et. al. [20, 21], namely, that pods with greater convexity are easier to be opened as the lower curvature radius causes an increase of the arm of the moment of pod shell bending in the perpendicular plane towards the direction of the location of fibres on the parchment layer. It shall be assumed that the susceptibility to cracking pods in the analysed varieties, is conditioned by other features [13].

Table 2. Average values sclerenchematic of bundles abdominal (A) and dorsal (D) seam on bean pods and their correlation coefficient with pods opening energy

Specification	Seam bundles	Narew	Nida	Warta	Wawelska	Correlation coefficients
Thickness [μm]	A D	178.4b 172.7ab	189.3bc 181.1b	157.6a 160.0a	194.2c 204.5c	-0.1952 0.0425
Width [μm]	A D	706.5cII 616.8bI	628.3bII 584.9bI	571.9aII 531.7aI	652.9bII 587.5bI	0.4458 0.2307
Surface of cross section [mm^2]	A D	0.129bII 0.108bI	0.120b 0.107b	0.092a 0.087a	0.128b 0.122c	0.1810 0.1509
Width/ Thickness	B G	4.24bII 3.79bI	3.57a 3.44b	3.88a 3.54b	3.60aII 3.02aI	0.6589 0.1108

* different letters in line and Roman numerals in column signify significant differences, as per LSD test (significance level of α = 0.05)

Analysing the results included in Table 2, it must be confirmed that the bundles of the abdominal seam were characterised by greater dimensions, section area and the ratio of width and thickness than the bundles of the dorsal seam, except for the varieties of Warta and Wawelska, in which the bundle of the dorsal seam was thicker. Statistically significantly wider were the bundles of the abdominal seam in all of the tested varieties. However, significantly, the greatest transverse section area of the abdominal suture bundle was characteristic of the pods of Narew variety, and the ratio of the width and thickness of bundles of the abdominal seam was significantly greater than in the varieties of Narew and Wawelska. With exception of the bundle width of the dorsal seam, the greatest dimensions and transverse section area were in the pods of Narew and lower in the pods of Warta varieties.

The bundles of the dorsal seam (Tab. 3) had a significantly greater damaging pressure, deformation and conventional module of elasticity from the bundles of the abdominal seam, except for the Wawelska variety in which an insignificantly greater value characterised the module of elasticity of the bundle of the abdominal seam. The sclerenchymatous bundles of the abdominal seam had the greatest resistance to tearing and deformations in the Warta pods, however, the greatest module of pod elasticity belonged to the Wawelska variety. The lowest stress, deformation and module occurred in the bundles of the abdominal seam in the Nida pods. The lowest stress and module for the bundles of the dorsal seam were noted in the pods of Warta and deformation in the variety of Narew. For the bundles of the dorsal seam, the greatest stress and module were noted in the pods of Warta and deformation in the variety of Narew, and the module of elasticity in the variety of Narew.

Table 3. Strength properties of sclerenchematic bundles abdominal (A) and dorsal (D) seam on bean pods and correlation coefficients of the energy pod opening

Specification	Seam bundles	Narew	Nida	Warta	Wawelska	Correlation coefficients
Critical stress [MPa]	A	84.95I	59.04I	105.57	90.03I	0.7049
	D	113.86II	121.02II	112.51	125.66II	-0.2476
Deformation [%]	A	5.52	4.99	6.69	5.35	0.3460
	D	6.49	7.96	7.75	7.46	-0.7811
Modulus of elasticity [MPa]	A	1875.8	1535.6	1715.3	1979.8	0.8951
	D	1977.0	1712.2	1600.9	1864.5	0.5887

*different letters in line and Roman numerals in columns signify significant differences, as per LSD test (significance level of $\alpha = 0.05$)

The energy of bean pod opening was positively correlated with the strength parameters of the abdominal seam bundles, however, much higher with the damaging stress and conventional module of elasticity and with deformation on average. It means that the varieties of beans whose bundles of sclerenchymatous abdominal seam are characterised with greater values of the analysed strength parameters need a greater energy of opening, i.e. they are less susceptible to breaking. The correlation indexes of the energy of opening with the damaging pressure and deformation of the bundles of the dorsal seam were negative, however, along with the module of elasticity, they were positive. The obtained values of correlation indicate that for the opening pods whose sclerenchymatous bundles of the dorsal seam are less resistant to tearing and undergo less deformations and are characterised with a greater module of elasticity, greater energy is needed.

The greatest thickness of the shell (282.4μm), parenchyma (183.1μm) and fibre layers (80.8μm) as well as the greatest ration of parenchyma thickness and layer of fibres (1.85) was noted in the pods of the variety of Wawelska (Tab.4). The thinnest shells (172.6μm), parenchyma (104μm), fibre layer (67.7μm) and the ratio of parenchyma thickness and layer of the fibres were characteristic of the pods of Nida. The pods opening energy was correlated very highly with the thickness of shell, parenchyma, and layer of fibres along with the ratio of parenchyma thickness and fibre layer.

Table 4. Average values thickness of fibre layer, shell pods and the ratio of parenchyma thickness and fibre layer, and correlation coefficients of the energy pod opening

Specification	Thickness [μm]			Ratio of parenchyma thickness and fibre layer
	Shell pods	Fibre layer	parenchyma	
Narew	232.6b	84.9b	147.7b	1.74c
Nida	172.6a	67.7a	104.9a	1.55a
Warta	187.5a	71.3a	116.2a	1.63b
Wawelska	282.4b	99.1c	183.3c	1.85d
Average	218.8	80.8	138.1	1.69
Correlation coefficients	0.7121	0.7045	0.7150	0.8018

* different letters in column signify significant differences, as per LSD test (significance level of $\alpha = 0.05$)

A positive correlation of the energy of bean pod opening of the examined bean varieties with the thickness of the fibre layer indicates that the thicker it is, the more difficult it is to open pods. However, the easiest opening of pods with a thicker layer of fibres was confirmed in the research on lupine pods [16, 24, 25] and lotus corniculatu, and siliqua. It may mean that the susceptibility to breaking in the pods of the tested varieties of beans are also determined by other features e.g. structure of cells – the more delicate and thinner walls, the weaker the cracking [25]. The very high correlation of opening energy with the thickness of parenchyma and the relation of the parenchyma thickness and fibre layers confirm the conclusions of the aforementioned researchers that the thicker is the part of the pod shell in relation to the fibre layer, the less susceptible fruits are to cracking.

The fibre layer of bean pods of Wawelska had the greatest resistance to tearing (170.3MPa) and deformations (8.2%). In the pods of Warta, however, the greatest module of pod elasticity was found (2296.9MPa). The lowest values of the determined strength parameters of the fibre layer were noted in the pods of Narew variety (damaging stress 119.18MPa, elongation by 6.13% and the module of elasticity 1958.75MPa).

The energy of bean pod opening was highly correlated with the stress damaging the layer of fibre and, on average, with their deformation and the module of elasticity. It may be confirmed that less susceptible to cracking are those pods whose fibre layer is determined by greater values of strength parameters.

Table 5. Strength properties of fibre layer bean pods and correlation coefficients of the pods opening energy

Varieties	Critical stress [MPa]	Deformation [%]	Modulus of elasticity [MPa]
Narew	127.9ab	6.28a	2040.5a
Nida	119.2a	6.13a	1958.8a
Warta	145.0b	6.35a	2296.9b
Wawelska	170.3c	8.20b	2078.8ab
Average	140.6	6.74	2093.8
Correlation coefficients	0.5052	0.3912	0.3575

* different letters in column signify significant differences, as per LSD test (significance level of $\alpha = 0.05$)

CONCLUSIONS

1. The pods which are the least susceptible to cracking are in the variety of Narew. They require significantly greater opening energy amounting to 258.1mJ. The most susceptible to cracking were the pods of Nida variety, where the necessary energy amounted to 125.1mJ.
1. The energy of bean pod opening was highly and positively correlated with the length (0.5335) and thickness (0.6505) of pods and negatively, on average, with their width (-0.3302) and almost fully with the shape index (-0.9256). It means that the bean varieties, whose pods are longer, narrower, thicker and with a less flat transverse section are more resistant to cracking.
2. The bundles of the abdominal suture were characterised by greater dimensions, section area and the ratio of width and thickness than the bundles of the dorsal seam, except for the varieties of Warta and Wawelska, in which the bundle of the dorsal seam was slightly thicker.
3. The bundles of the dorsal seam had a significantly greater damaging pressure, deformation and conventional module of elasticity than the bundles of the abdominal seam, except for the variety of Wawelska in which an insignificantly greater value was observed in the module of elasticity of the bundle of the abdominal seam.
4. For the pods of bean varieties whose sclerenchymatous bundles of the abdominal seam had greater values of the analysed strength parameters, whose sclerenchymatous bundles of the dorsal seam were less resistant to tearing and underwent fewer deformations and were characterised by a greater module of elasticity, greater energy was needed.
5. The pods with a thicker fibre layer, shell and parenchyma along with the greater ratio of parenchyma and layer of the fibres, required greater energy of opening.
6. The fibre layer of bean pods of Wawelska had the highest resistance to tearing (170.3MPa) and deformations (8.2%). In the pods of Warta, however, the greatest module of pod elasticity was found (2296.9MPa). The lowest values of the determined strength parameters of the fibre layer were noted in the pods of Narew variety: damaging stress 119.18MPa, elongation by 6.13% and the module of elasticity 1958.75MPa.
7. The energy of bean pod opening was highly correlated with the stress damaging the layer of fibre and, on average, with their deformation and the module of elasticity, i.e the pods whose fibre layer was characterised by greater values of strength parameters were less susceptible to cracking.

REFERENCES

1. **Burski Z., Tarasińska J., Sadković R. 2003**: The methodological aspects of using multifactoral analysis of variance in the examination of exploitation of engine sets. TEKA Komisji Motoryzacji i Energetyki Rolnictwa Polskiej Akademii Nauk Oddział w Lublinie, 3, 45-54
2. **Ciupak A., GładyszewskaB., Dziki D. 2012**: Change in strength of tomato fruit skin during ripening process. TEKA. Commission Of Motorization And Energetics In Agriculture, 12(2), 13-18.
3. **Dorna H., Duczmal K. W. 1994**: Influence of climatic conditions on the formation of the fibers in the seams of the bean pods *Phaseolus vulgaris* L. (in Polish). I Ogóln. Konf. Nak. Strączkowe Rośliny Białkowe. FASOLA, Lublin 25.11.1994, 135-138.
4. **Dziki D., Laskowski J. 2006**: Influence of wheat grain mechanical properties on grinding energy requirements TEKA Kom. Mot. Energ. Roln., 6A, 45-52.
5. **Esau K. 1973**: Anatomy of plants (in Polish). PWRiL, Warszawa, 1973.
6. **Furtak J., Zaliwski A. 1986**: Studies on the mechanical harvest of seeds (in Polish). Roczniki. Nauk Rolniczych, ser. Technika Rolnicza, 2, 127-140.
7. **Gorzelany J., Puchalski C. 2010**: Mechanical properties of roots in selected sugar beet varieties (in Polish). Inżynieria Rolnicza. 1 (119), 199-204.
8. **Guz T. 2008**: Thermal quarantine of apples as a factor forming its mechanical properties. TEKA Komisji Motoryzacji i Energetyki Rolnictwa Polskiej Akademii Nauk Oddział w Lublinie, 8a, 52-62.
9. **Hejnowicz Z. 1985**: Anatomy and vascular plants histogeneza (in Polish). PWN, Warszawa.
10. **Kuźniar P., Sosnowski S. 2002**: Relation between the bean pod shape factor and force required for pod opening. International Agrophysics, 16(2), 129-132.
11. **Kuźniar P., Strobel W. 2000**: Determine the effect of thickness sclerenchyma bean pods on their susceptibility to cracking (in Polish). Acta Agrophysica, 37, 113-117.
12. **Kuźniar P., Sosnowski S. 2003**: Susceptibility of bean pods on cracking and losses of seeds during mechanical harvest (in Polish). Acta Agrophysica, 2(1), 113-118.
13. **Kuźniar P., Sosnowski S. 2007**: The attempt of measuring the air volume in bean pods. TEKA Commission of Motorization and Power Industry in Agriculture, 7A, 68-72
14. **Kuźniar P. 2008**: The energy of bean-pod opening and the method of determining air volume therein. MOTROL- Motoryzacja i Energetyka Rolnictwa. 10, 73-77.
15. **Kuźniar P. 2012**: Energy of bean pods opening with phosphorous fertilization. TEKA Commission of Motorization and Energetics in Agriculture. 12(1), 131-134.
16. **Moś M. 1983**: Variability of morphological and anatomical features of the pod, its impact on the propensity to crack and seed yield of birdsfoot ordinary *Lotus cor-*

niculatus L. (in Polish). Zeszyty Problemowe Postępów Nauk Rolniczych, 258, 197-203.

17. **Strobel W. 2003**: Comparison of the physical characteristics of pods of different lupine species (in Polish). Zeszyty Problemowe Postępów Nauk Rolniczych, 495, 73-80.
18. **Szot B., Tys J. 1979**: The reasons for shedding the oilseeds and legumes and methods of assessment of this phenomenon (in Polish). Problemy Agrofizyki, 29.
19. **Szot B., Tys J. 1987**: Test methods are the mechanical properties of rape siliques and stems (in Polish). Zeszyty Problemowe Postępów Nauk Rolniczych, 321, 193-202.
20. **Szwed G., Strobel W., Tys J. 1997**: The mechanisms governing the processes of cracking lupine pods (in Polish). Mat. Konf. Łubin we współczesnym rolnictwie, Olsztyn 25-27.06.1997,107-112.
21. **Szwed G., Tys J., Strobel W. 1999**: Pressurized methods for grading the vulnerability of pods splitting. International Agrophysics, 13, 391-395.
22. **Szymanek M., Sobczak P. 2009**: Some physical properties of spelt wheat seed. TEKA Komisji Motoryzacji i Energetyki Rolnictwa Polskiej Akademii Nauk Oddział w Lublinie, 9, 310-320.
23. **Tomaszewska Z. 1954**: Initial studies on the anatomy of pods of lupine (in Polish). Acta Agrobotanica, 2, 151-171.
24. **Tomaszewska Z. 1964**: Morphological studies and anatomical of siliques of several varieties of winter oilseed rape and turnip rape, and reasons and mechanism of their cracking (in Polish). Hodowla Roślin, Aklimatyzacja i Nasiennictwo, 2, 147-180.
25. **Tomaszewski Z. 1953**: Breeding of yellow lupine which pods do not crack and not fall off (in Polish). Acta Agrobotanica, 1, 89-104.

ENERGIA OTWARCIA STRĄKÓW FASOLI A WŁAŚCIWOŚCI WYTRZYMAŁOŚCIOWE WYBRANYCH ELEMENTÓW ICH BUDOWY

Streszczenie. Praca przedstawia analizę korelacji energii otwarcia strąków fasoli odmian Narew, Nida, Warta i Wawelska z ich cechami geometrycznymi oraz właściwościami wytrzymałościowymi wybranych elementów ich budowy. Stwierdzono, że bardziej podatne na pękanie są strąki; o bardziej płaskim przekroju (szersze i cieńsze); o mniejszej grubości warstwy włókien i parenchymy oraz mniejszym stosunku grubości parenchymy i warstwy włókien; których warstwa włókien ulega mniejszym odkształceniom i jest mniej wytrzymała na rozrywanie; których wiązki sklerenchymatyczne szwu grzbietowego są bardziej wytrzymałe na rozrywanie, a szwu brzusznego mniej.

Słowa kluczowe: strąk fasoli, elementy budowy, właściwości wytrzymałościowe, energia otwarcia.

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