THE INFLUENCE OF SELECTED FACTORS ON THE NUMBER OF CONTACTS BETWEEN SEEDS

Jarosław Frączek, Zbigniew Ślipek, Marek Wróbel
Department of Mechanical Engineering and Agrophysics, Agricultural University of Cracow

Abstract. The relationship between the mean number of contacts between stored seeds, NC_{mean}, with its main determining factors, namely moisture content, pressure and grain shape, was investigated for lentil, vetch, white mustard, bean, wheat, triticale and rye seeds. Two methods were used: a modified Bernal-Mason method and a method employing computer imaging. Each was used for both poured and shaken deposits of seeds. The results demonstrate that, apart from moisture content and pressure, the main factor affecting the NC_{mean} value is seed shape. As the elongation or flattening of seeds increases, so does the NC_{mean}.

Key words: seeds, contact points, granular materials, shape coefficient

Introduction

Granular materials are ubiquitous in the environment, industry, and agriculture. It is hard to find an area of human activity where the properties of these materials do not play a significant role. Geological processes, landslides, erosion, avalanches, material engineering, mining, agriculture, and the food industry are just a few examples of events and activities in which they are involved. In most cases the particles that compose granular materials are irregularly shaped. In the case of regular particles, there are known relationships between the particle size, its shape, the number of contacts per particle, packing density and other properties. In the case of irregular particles, there is less predictability in relationships. The present paper is an attempt to establish connections between the properties of irregular granular materials and their determining factors in the specific case of plant seeds. With seeds there are more potential determining factors than for other materials, includung moisture content and the ability of seeds to change shape.

The aim was to establish the relationship between the average number of seed contacts with other seeds *(NC_{mean})* and the most significant factors determining this value; these were considered likely to be moisture, external pressure and seed shape.

Material and methods

Two methods of producing the sample were considered, i.e. pouring and shaking. A working hypothesis was expressed as:

$$NC_{mean} = f\,(KS, M, p_n) \tag{1}$$

where:

NC_{mean} – average number of seed contacts,
KS – the seed shape parameter,
M – seed moisture,
p_n – pressure.

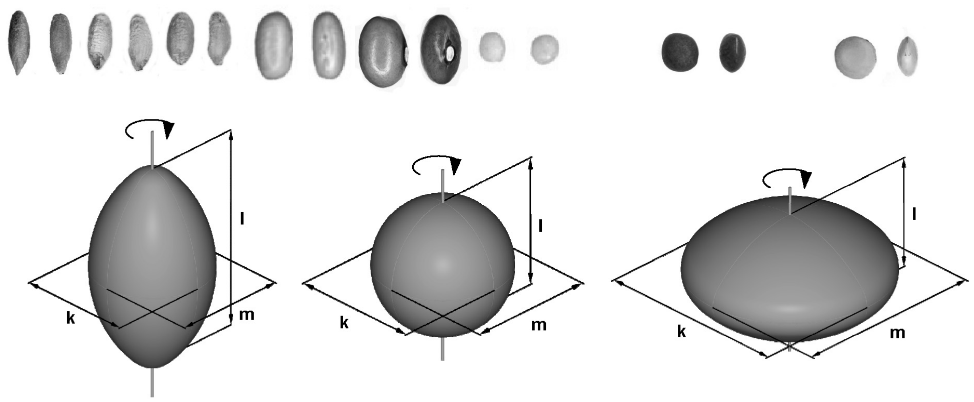
The measurements were made on the poured and shaken deposits of seeds of eight cultivated plants: Anita lentil (*Lens culinaris* Medik.), Szelejewska common vetch (*Vicia sativa* L.), Nakielska white mustard (*Sinapis alba* L.), Jubilatka and Atena common bean (*Phaseolus vulgaris* L.), Roma wheat (*Triticum* L.), Vanad triticale (*Triticale* Muntzig), and Dankowskie Zlote rye (*Secale* L.). Shape parameter shape coefficients α and β were adopted from Donev et al. (2004a and b):

$$\alpha = \frac{l}{k} \tag{2}$$

and

$$\beta = \frac{m}{k} \tag{3}$$

where *k, l* and *m* are axes of ellipsoids that describe the seeds (Fig. 1).



Source: author's elaboration

Fig. 1. Shapes of seeds and types of ellipsoids with the nomenclature of axes

On the basis of the foregoing equations, the authors proposed a new shape coefficient, α_m:

$$\alpha_m = \frac{l}{\frac{k+m}{2}} = \frac{2 \times l}{k+m} \tag{4}$$

where: *k, l, m* are dimensions of the seed (see Fig. 1).

The values of α_m unambiguously classify the seed shape, such as flattening or elongation (table 1).

Table 1. Shape coefficient α_m

Variety	Shape coefficient α_m
Anita lentil	0.44
Szelejewska common vetch	0.78
Nakielska white mustard	1.17
Jubilatka common bean	1.51
Atena common bean	2.01
Roma wheat	2.12
Vanad triticale	2.39
Dankowskie Zlote rye	2.93

Source: author's calculations

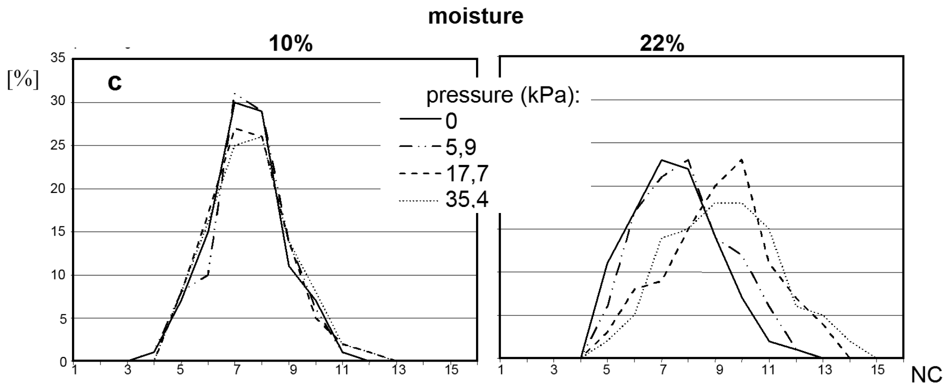
No methods have previously been developed for *NC* measurement between seeds. In the present study, the Bernal & Mason (1960) method was attempted. This method was originally designed for a deposit of steel spheres of identical size, and consisted of pouring paint over the deposit, which, after draining, marked the place and nature of the contact by remaining on the spheres' points of contact. The merit of this method is the ease of measurement and the unambiguous information on the number of contacts for each particle.

Preliminary testing established that the above method could only be used for seed moisture > 14%. In the case of seeds < 14% moisture, it was impossible to establish whether the seeds were either touching or almost touching. This issue was elaborated by Fraczek & Wrobel (2006). Thus it was necessary to develop a new method. The *NC* measurement for seed moisture < 14% was based on the assumption that the points of contact could be found and counted in analyses of the sequences of cross-sectional images of the granular structure. The measurement procedure has been presented in the authors' publication [Fraczek & Wrobel 2007].

Results

Unlike regular granular patterns, where there is a constant number of contact points per particle, in materials with a less regular pattern only an average number of contacts per particle can be established. Exemplary values of the *NC* from the tests are shown in Figure 2.

For low moisture, the pressure did not significantly affect the *NC*, while for moisture of 22%, there were apparent changes in the *NC*.



Source: author's elaboration

Fig. 2. Numbers of contacts (moisture 10% and 22%) for the Atena common bean

In the case of seeds with an approximately spherical shape, there was a leftward movement of the histograms, e.g. for mustard seeds, *NC*=5 for about 30% of seeds, in comparison to flat or elongated seeds, which is consistent with other studies (Abreu et al. 2003; Donev et al. 2004b; Williams & Philipse 2006). The theoretical maximum number of points of contact of spherical particles is 12; for flat or elongated ellipsoids, it is larger.

In the case of non-pressed, poured deposits, the increased seed moisture caused a slight decrease in the *NC*. This phenomenon can be explained by increased friction between seeds from increased moisture; the gravity is lower than the inner friction, and the seeds become more interlocked. In the case of the shaken deposits, there was no similar tendency, as the vibration probably caused the seeds to be better packed.

Increased pressure and moisture increased the *NC*. The maximum value (NC_{max}), was characteristic for a given type of deposit, moisture and pressure.

The method of creating the deposit affected the NC_{max} value. The difference between the minimum and maximum *NC* for the shaken deposits was significantly smaller than for the poured deposits. For example, the relative *NC* growth for vetch is 12.9% for shaken deposits and 26.2 % for poured deposits.

To test the hypothesis, non-linear models were fitted using the Statsoft Statistica v.6.0 program. The seeds were divided into 4 groups, on the basis of their shape and type:

- I – lentil and vetch.
- II – mustard.
- III – beans.
- IV – wheat, triticale and rye.

The results from the measurements were approximated separately for each group, taking into account moisture, pressure, shape and deposit type. The best-fitting function was:

$$NC_{mean} = (\alpha_m^{\ a} \cdot M^c \cdot p_n^{\ e}) + d \qquad (5)$$

where:

- NC_{mean} – average number of seed contacts,
- α_m – the shape coefficient of the seed,
- M – seed moisture,
- p_n – pressure.
- a, c, d, and e – constants

Using four separate models gave much better estimates for both poured deposits (table 2) and shaken deposits (table 3).

Table 2. Results of fitting the non-linear model $NC = (\alpha_m^{\ a} \cdot M^c \cdot p_n^{\ e}) + d$, for poured deposits

Group	Constant	Value	Standard error	*P* level	Lower confidence limit	Upper confidence limit	R^2
I	A	-1.90	0.281	0.000	-2.466	-1.343	0.758
	C	0.48	0.176	0.008	0.133	0.835	
	E	0.04	0.011	0.000	0.019	0.063	
	D	6.10	0.197	0.000	5.706	6.494	
II	A	17.72	4.186	0.000	9.150	26.299	0.859
	C	2.39	0.427	0.000	1.519	3.266	
	E	0.46	0.103	0.000	0.250	0.671	
	D	5.73	0.093	0.000	5.540	5.920	
III	A	1.03	0.384	0.009	0.263	1.800	0.765
	C	2.02	0.306	0.000	1.412	2.637	
	E	0.89	0.130	0.000	0.632	1.150	
	D	7.32	0.073	0.000	7.178	7.471	
IV	A	1.29	0.068	0.000	1.157	1.428	0.668
	C	0.12	0.051	0.025	0.015	0.219	
	E	0.01	0.003	0.000	0.005	0.017	
	D	4.59	0.171	0.000	4.247	4.925	

Source: author's calculations

For both poured and shaken deposits, the values of constant a were negative when $\alpha_m < 1$, and positive when $\alpha_m > 1$. This indicated that the increased flattening and elongation of seeds is associated with an increased NC_{mean}.

The constant *c* was always positive, indicating that increased moisture resulted in increased NC_{mean}. Group II displayed the highest values of *c* (poured deposit 2.39, shaken deposit 2.28), and group IV showed the lowest (poured deposit 0.12, shaken deposit 0.06).

The constant *e* was positive, but lower than *c* in all cases. This may indicate that pressure had less influence on the NC_{mean} than moisture.

The constant *d* is the minimum number of contacts characteristic for a given group; its value increased with the increased flatness or length of seeds.

Table 3. Results of fitting the non-linear model $NC = (\alpha_m^a \times M^c \times p_n^e) + d$, for shaken deposits

Group	Constant	Value	Standard error	*P* level	Lower confidence limit	Upper confidence limit	R^2
I	A	-1.81	0.271	0.000	-2.349	-1.265	0.787
	C	0.58	0.176	0.002	0.224	0.927	
	E	0.04	0.009	0.000	0.017	0.054	
	D	7.93	0.159	0.000	7.616	8.251	
II	A	13.51	5.477	0.020	2.294	24.734	0.757
	C	2.29	0.569	0.000	1.121	3.451	
	E	0.37	0.131	0.008	0.102	0.637	
	D	7.09	0.061	0.000	6.966	7.217	
III	A	2.24	0.373	0.000	1.496	2.986	0.675
	C	0.65	0.223	0.005	0.204	1.098	
	E	0.03	0.010	0.003	0.010	0.049	
	D	7.90	0.224	0.000	7.451	8.346	
IV	A	1.58	0.031	0.000	1.520	1.643	0.929
	C	0.058	0.022	0.009	0.015	0.101	
	E	0.003	0.001	0.012	0.001	0.005	
	D	5.21	0.096	0.000	5.024	5.405	

Source: author's calculations

Conclusions

1. The new shape coefficient, α_m, classified the all analized seeds and took all the main seed dimensions into account.
2. The factors which determined the NC_{mean} in a deposit were shape coefficient, moisture and pressure, and were described by the function: $NC_{mean} = (\alpha_m^a \cdot M^c \cdot p_n^e) + d$
3. The analyses showed that it is possible to group seeds according to their shape and type for the purpose of predicting the NC_{mean}. The hypothesis was verified by the analyses.

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WPŁYW WYBRANYCH CZYNNIKÓW NA LICZBĘ PUNKTÓW STYKU POMIĘDZY NASIONAMI

Streszczenie Materiały ziarniste są jednymi z najpopularniejszych materiałów występujących w przyrodzie, przemyśle i rolnictwie. Elementy struktury tych materiałów pozostają w układzie regularnym bądź, w przeważającej większości przypadkowym. Celem prezentowanych badań było określenie zależności pomiędzy średnią liczbą punktów styku nasion LS_{sr} a najistotniejszymi czynnikami ją determinującymi tzn.: wilgotnością, wartością nacisku oraz kształtem nasion. Pomiary wykonano na nasionach roślin uprawnych: soczewicy, wyki, gorczycy białej, fasoli, pszenicy, pszenżyta i żyta. Liczba punktów styku wyznaczona została wg dwóch metod: zmodyfikowanej metody Bernala-Masona oraz autorskiej metody opartej na komputerowej analizie obrazów. Każda z nich została zastosowana dla złóż nasion w stanie usypowym i utrzęsionym Powyższa analiza wskazuje, że głównym czynnikiem, obok wilgotności i nacisku, wpływającym na wartość LS_{sr} jest kształt nasion. Wraz ze wzrostem wydłużenia bądź spłaszczenia nasion wzrasta również LS_{sr}.

Słowa kluczowe: nasiona, punkty styku, materiały ziarniste, współczynnik kształtu

Mailing address:
Marek Wróbel; e-mail: Marek.Wrobel@ur.krakow.pl
Department of Mechanical Engineering and Agrophysics
Agricultural University of Cracow
Balicka 120
30-149 Cracow
Poland