VARIABILITY OF THE MECHANICAL PROPERTIES OF CEREAL PLANTS

Bogusław Szot

In recent years the mechanical properties of cereals have been the subject of particular interest on the part of specialists from many branches direcily or indirectly connected with production. The increasing demand for cereals and their products puts before agriculture the difficult tasks of increasing production, while the dynamic development of industry and building construction systematically restricts the agriculturally productive area. One of the solutions is its maximum utilization through introducing intensive varieties, improving the technologies of harvesting and storage, and creating optimal conditions of cultivation. Analyzing the whole cycle of cereal production, it was found that the greatest quantitative losses of grain occur during harvesting and are caused by the falling of seeds, by leaving some unthreshed grains in the ears, and by mechanical damage. This is confirmed by numerous investigations and by observations carried out by practitioners. Hence arises the problem of not only breeding highly productive varieties but also of programming such a technology of cultivation and harvesting that the full quantity of produced grain can be collected and be of high quality.

One of the causes impeding the limitation of the losses to the minimum is the lack of sufficient information about the mechanical properties of cereal plants and their variability determined by a system of many external and internal factors. In turn the very wide range of variability of these properties additionally complicates the optimization of the technological processes.

Characterization of the mechanical properties of not only the grain of cereals, but also of all plant materials, creates undoubtedly serious difficulties of both theoretical and experimental nature. Heterogeneity of plants and agricultural crops does not allow for the direct application of classical notions of physics for describing the parameters that are of interest to us. The very complex, multiphase structure of living organism,

such as plants during vegetation or already collected grain will not always allow, even for attempts at theoretical solving, the courses of the physical processes. Thus it becomes a necessity to carry out numerous phenomenological investigations, often based on intuitional choice of properties and on looking for mutual interrelationships among them.

So far there is no detailed classification of all the physical parameters, interesting from the theoretical and practical point of view in relation to particular varieties of plants or to certain groups of particular properties in common. In the literature of the subject much attention was paid to the mechanical properties the knowledge of which is of the importance for practice and is the starting point for the inspiration of investigating the remaining properties.

On the basis of papers sent to the Conference it is possible to separate a group of mechanical properties of cereals which seems to constitute the minimum necessary to get to know the parameters that are the most important from the point of breeding new varieties, cultivation, harvesting technology, transportation and storage.

This group contains the following properties:

1. The susceptibility of cereals to the falling of grain.
2. The grain-to-ear binding force.
3. Energy needed to remove grain from ear.
4. The basic geometrical features of grain.
5. The resistance of grain to mechanical loading.
6. Extent of deformations of grain caused by immediate loading.
7. Energy causing deformations.
8. Grain layer porosity.
9. Interial porosity of grain.

Knowledge of parameters determining the susceptibility of cereals to the falling of grain and the grain-to-ear binding force is necessary both for the breeders of varieties of favourable properties and for the mechanizers, whose task is to lower the losses occurring during harvesting. During the period of ripening many factors can cause the falling of grain, particularly the variable atmospheric conditions and the mutural hitting of ears. During harvesting the weakest bound grains can fall already at the moment of contact with the rakes or the cutting systems of harvesters. In turn in the case of too strong a bond between grain and the ear torus the working parameters of the threshing system can be insuffucient, and some grain remains with straw. Thus the determination of the variability limits for this important property of careals can largely influence the limitation of the quantitative losses of grain.

In recent years many works were devoted to these problems. From among the numerous investigation methods the most common ones can

be divided into the direct and indirect ones. The first group comprises vibrational, shock and centrifugal methods. The indirect methods are based on measurements of forces binding particular grains.

Investigations carried out with the help of vibration apparati with determined time of measurement, amplitude and frequency of vibrations do not allow for the recording of the absolute values of force. The only index is the percentage of the grains that have fallen in relation to those that have remained in the ear. The obtained results indicated the high applicability of this method, but only for comparative purposes between varieties, or for the determination of relative susceptibility to the falling of grain at different dates of harvesting. For instance, it was found the varialibity of this property within one species is very high and, for the investigated varieties, forms the range of from 0 to 30% of fallen grain at identical parameters of measurement. Varieties of low compactness of the ear turned out to be particularly susceptible to the falling of grain. The information so far obtained induces to the application of the vibration method for comparative purposes particularly if a large number of varieties is to be evaluated in a short period of time. This allows also for the choice of appropriate material for more precise investigations.

One of the indirect methods also allowing for rapid making of a large number of measurements — both in field and laboratory conditions — is the shock method with the application of a threshability classifier, also called the Pustygin's apparatus. The construction of the apparatus enables a dynamic character of measurement, and obtained results allow for a direct determination of the value of the force causing the threshing of grain on the basis of its weight and the speed of falling of the lever with an ear fixed to it.

With the centrifugal method the value of the force is calculated also in a indirect way, knowing the number of the rotations of the drum of the centrifuge to which the ears are fastened.

Results of investigations of this type were tentatively applied for the choice of regulation parameters of harvesting-threshing machines, simultaneously recording the losses of grain caused by the falling of grain and part of it remaining in the ears.

The direct method is one of the most recent and at the same time one of the most complicated. It was worked out by a team of scientists under the direction of Prof. Řezníček — the Director of the Institute of Physics of the High School of Agriculture in Prague. Then it was developed and applied in the Institute of Agrophysics of the Polish Academy of Sciences in Lublin, where a prototype measuring apparatus was also worked out and constructed. At present this apparatus is being used for investigations in several scientific centres in Poland.

The most important advantage of this method is the possibility of obtaining very exact results in absolute values of force and the levels of energy consumption. Measurements of the force binding single grains give additionally the characterization of the variability of this property in the whole ear. Thus they can be related to particular parts of the ear and connected with the changeability of ripening.

The hitherto utilized apparatus consisted of three different devices working on different principles. The prototype of the Czech micropicker operates on the principle of a tensometric system. The electromagnetic micropricker made in the Institute of Agrophysics of the Polish Academy of Sciences operates on the principle of amplifying electric current in the circuit of an electromagnet, and thus increasing the force. The third way is utilization of the „Instron" apparatus by constructing special equipment fixed to the measuring heads.

During recent years numerous series of measurements were carried out and the methodology improved. The close cooperation of the Institute of Agrophysics in Lublin with the earlier mentioned Institute of Physics in Prague, begun four years ago, enabled a full confrontation of measuring methods and apparati, the result of which is a unified, as to details, course of proceedings during investigations. The obtained results allowed both for an exact characterization of the investigated material grown in both countries and for the evaluation of the apparatus. It was proved that the character of the variability of the grain-to-ear binding force is identical with the application of three different apparati.

A very high variability of the force on the length of the ear was established. Grains are bound the strongest in the middle part of the ear, less strongly in the lower part, and the weakest in the upper one. The calculated variability coefficients are over 35%. So considerable a differentation is undoubtedly the cause of high losses of grain during harvesting, if proper parameters of the working systems of harvesting machines are not chosen. This is connected with the necessity of getting to know the interspecies and intervariety changeabilities. It follows from the carried out investigations that they form very wide ranges, which become still wider with the delaying of the date of harvesting.

Also an introductory characterization of the grain-to-ear binding force has been done for the new form of cereal plant — *Triticale*, on the basis of the evaluation of several tens of varieties being the object of breeding. The obtained results enable the evaluation of a vast breeding material already in the first stages of selection from the point of appropriate direction of further investigations. It was found that many variaties have a much stronger grain-to-ear bond than wheat or rye. This can

be connected with a large number of grains remaining in the ears if in appropriate working parameters of threshing machines are chosen.

Of all the apparati applicable for investigating the grain-to-ear binding force only the micropicker worked out in the Institute of Physics in Prague and the resistance measuring apparatus "Instron" in the Institute of Agrophysics in Lublin allowed for continuous recording of measurement in progress. On the basis of the obtained diagrams it is easy to determine the minimum of energy needed to remove grain from ear. The knowledge of this parameter is also extremely valuable for agricultural practice. The values of energy have much greater variability than the grain-to-ear binding force. It was found that energy necessary to remove grain from among the surrounding chaffs in some varieties of wheat and *Triticale* is much greater than the energy needed to break it off from the ear torus. This phenomenon does not occur only in the case of rye, where a considerable part of the grain is not chaffed.

Thus the question arises whether for a complete characterization of the susceptibility to the falling of grain and the threshability of cereals the bare knowledge of the variability range of the force binding grain to the ear tours is enough, or also the more precise evaluation including the energy as well.

Another problem recurring in some works on the subject is the evaluation of the size of grain. The size and fullness of seeds were hitherto a rather subjective and imprecisely described index of quality and usability value. There were also, often chosen purely intuitively, the parameters of the cleaning and sorting machines for the separation of the "bad quality grain", the limits of which were at least problematic.

In recent years — together with the development of investigations of the mechanical properties of cereals — the importance of the size of grain greatly increased, since it was found that this property influences the variability of many others, that are very important from the point of practice. This primarily concerns the resistance to mechanical damage and the position of grains in mass during the processes of drying and storage.

However the characterization of the size of grain turns out to be very difficult from the mathematical point of view, since grain is of irregular shape of considerable variability. Some attempts at theoretical solving of this problem have not yielded any satisfactory results yet. That is why describing the size of grains three basic dimensions are so far accepted: the smallest — thickness, the greatest — length, and the medium one — width.

The applied methods of measurements so far can be described as very tiresome, work consuming, or giving only approximate values. The

measuring system worked out in the Institute of Agrophysics in Lublin enables the obtaining of results with high exactness and in the full range of the occurring variability for cereals. The obtained distributions of the investigated parameters both close to normal and showing asymetry, were used for an introductory analysis of grain quality according to the statistical criteria of evaluation. Significant correlations were found among the investigated values and also a considerable influence of external factors determining the high variability of the material. It should be expected that further research in this direction will enable not only a measurable evaluation of quality but first of all will provide an answer to the question which of the factors have the most favourable influence on the qualitative and quantitative properties of grain.

As was mentioned earlier, in the light of recent research the resistance of grain to mechanical damage is closely related to its size, and within particular size groups to the properties of the species and varieties. An extremely important role is played here by the moisture level, greatly extending the range of variability.

In the literature of the subject the resistance of grain to deformations is mainly treated as a function of hardness. The used methods of measurement of this property are, however, very differentiated and sometimes very difficult because of too small an object and the irregularity of its shape. Investigations carried out in a mass of grain did not give the expected results because the obtained results could not be related to the actual physical state in which the particular grains are during the process of threshing. It seems more appropriate to get to know well first the properties of single grains, so as to be able to approach their evaluation in mass already with the information.

The apparati used in Poland for investigating single grains are based on the concept of a mechanical system compressing the grain with the help of two parallel planes under the conditions of a quasi-static loading. The parameters of the susceptibility of grain to damage can be determined from the recorded characterization of the course of measurement of deformation in the function of loading. The obtained values were described as the immediate resistance of grain to static loading, which the value of force damaging the structure of grain by disturbing its cohesion. This fact is connected with the extent of the immediate deformations.

Because of the lack of adequate terminology describing the deformations of grain the term "immediate" was accepted as implying the process of deformation occuring in a quasi-linear way, allowing however for the existence of histeresis. It should be stressed here that the determination of an exact limit of elasticity for plant materials is still an open question. The proposals presented in the literature of the subject have,

even in the opinion of their authors, a certain margin of error, which follows from the specific and heterogenous anatomical build up of plants and agricultural crops in comparison with homogenous materials.

The discussed parameters are closely connected with the determination of energy causing the immediate deformations. Its value is characteristic for various physical states of grain, species and varieties. The determination of the absolute values of energy is based on known methods, with the application of apparati integrating the area limited by the curve of the change of force in function of distance in the Cartesian system.

Investigations of the resistance of grain to loading, the extent of deformations and the energy that causes them are carried out in Poland on a large scale with the help of prototype apparati and the resistance measuring "Instron".

The obtained results comprise an analysis of a very large experimental material. The range of variability of these properties is extremely wide and depends not only on the species, variety, geometrical dimensions, glassiness and moisture of grain, its origin from different ecological conditions, but also on the mutual, relationships among the particular factors of agrobiological and physical nature.

The mean limit values showed even ten times higher resistance of grain to damage during comparisons of two investigations on objects of different physical states and biological properties.

The conclusions that follow from the above can have a vast importance, particularly for producers of sowing material, on the quality of which the crop yields undoubtedly depend. It is generally known that damaged grain is not only more susceptible to infection by microorganisms, but their biological value becomes much lower, or disappears completely.

Another problem from the interest range of authors is the evaluation of the porosity of cereal grain layer and the range of its variability. This property plays an important role in the process of drying, where the transition of the drying medium is dependent on the resistance created by the porous mass. In storage the porosity parameters determine the possibilities of storing grain. Too little porosity is dangerous and can cause the occurrance of unfavourable procceses, the effects of which is, in the first stage, the lowering of the quality of the material of even the loss of its usability value. These problems become particularly important with the exploitation of silos of great volume and with storing grain for long periods.

The porosity of a layer of grain depends on their shapes, sizes, state of surface, situation in mass, moisture and the quantity of contaminating matter. During the filling of large containers with grain there occurs the phenomenon of self-sorting, which locally changes the content of pores.

We do not know yet the exact influence of temperature and the relative moisture of air on the variability of this property of grain mass. The scarce information on the subject so far confirms the assumption that it is important.

The known methods of determining porosity are based first of all on filling the free inter-grain spaces with various liquids in grain samples of known volume. Most often liquids that do not cause changes in the volume of grain, like alcohol, petroleum or oil, are used for this purpose. Also the pycnometric method, allowing for the determination of the specific gravity of grain and for the calculation of the total porosity with the known pouring weight, is also applied.

Among the most recent there is the rapid method with the application of the pressure porometer, also used in investigating soil porosity.

On the basis of the investigations carried out, comprising material originating from various soil-climatic conditions and from experiments of differentiated agrotechnological factors, a wide range of variability of this property was proved. Significant differences occured in the comparisons of the majority of the mean values. An extremely important role is played here by the size of grain, characterized by the three basic dimensions. The measurements carried out on fractioned material proved that the smaller the grain the greater the porosity of its mass. The calculated coefficients of correlation between these two values are up to 0.99. This relationship is true also for grain of natural granulometric composition. Varieties of small anr undeveloped grains have much greater porosity than a layer of grain of high quality.

The method worked out creates the possibility of determining this property rapidly in the range of all the varieties of the basic cereals.

Extending the investigations, as analysis of the influence of static loading on the variability of cereal grain layer porosity has been carried out. The phenomenon occurs mainly in the lower parts of silos, and also during transportation of large quantities of grain.

The process of static loading was realized with the help of the resistance — measuring apparatus "Instron" at a constant rate of deformations. The character of the course of the curve at the loading of a layer of grain, which corresponded to the curve of comprimation of other loose media, was obtained from the recorder of the apparatus. The investigation material diminished its level of porosity through gradual compaction. On this basis the relation between deformation and porosity was determined. Theoretical considerations confirmed the experimental data. In connection with this for every value of loading — corresponding to a certain deformation — appropriate value of porosity was determined.

This gave a characterization of the variability of porosity in the function of loading, which shows high variability in dependence on the species and varieties of cereals.

Also investigations of the interial porosity of grain were initiated with the assumption that the quantity of pores, their volume and distribution can have a significant influence on the important mechanical parameters of grain, such as resistance to loading, hardness, elasticity, plasticity and also the course of a group of biological processes occurring after harvesting. The spatial distribution of pores determines also the intensity of the heat and mass exchange, which in turn is one of the basic problems in drying and storage.

The method of determining the volume of pores in grain has been based so far on microscopic analysis of its anatomical build up. On this basis it was accepted that the free spaces between the cells and tissues smaller than 1 000 Å shoul be treated as micropores, and those greater than this value — as macropores. This division was connected with the movement of water in grain, assuming, that with macropores the forces of surface tension are lower than the force of gravity. This information very poorly presented the physical structure of grain.

In recent years in the Institute of Agrophysics of the Polish Academy of Sciences in Lublin, a method for the determination of the interial porosity of grain was worked out. It allows for measurements in a very wide range, from 30 to 1 000 000 Å of the capillary radius. This range probably comprises all the pores that occur in cereal grain. The investigations were carried out with the help of the Italian mercury porosimeter Carlo Erba, so far utilized in the chemical and metalurgical industries.

The obtained results of measurements characterize the variability of this property as determined by many factors, first of all the interspecies and inter-variety differences, and the local conditions in which the cereals were grown. A close correlation between the content of certain groups of pores and the resistance of grain to mechanical damage was established.

It should be expected that further investigations and a deeper analysis of the obtained results will create a possibility of evaluating other important properties of grain on the basis of the obtained distributions.

The presented range of problems does not comprise all the works connected with investigating the mechanical properties of cereals. Other properties will be discussed in one of the following papers.

In relation to the mentioned problems a number of questions requiring a wide presentation and discussion appear.

Methods of determining the mechanical properties of cereal plants

are various and based on different assumptions. Hence the obtained results are often incompatible and do not create any possibilities of confrontation. Thus arises the necessity, and at the same time a proposal, of establishing an unified methodology of investigations on the basis of commonly accepted assumptions.

A no less important matter is the terminology. Characterization of various processes and phenomena describing the behaviour of plant material under the influence of exterial action seldom finds proper reflection in terminology used in the mechanics of homogenous materials. Hence the appearance of new formulations that become more and more numerous in the literature of agrophysics. The establishment of a systematized terminology in several languages becomes a necessity that should not be put off any longer. This would also simplify the understanding of mutual intentions in scientific cooperation.

An important matter is a proper directing of investigations, both basic and applied. Mutual agreements enabling the many sided approach to the problems seems necessary. The very high variability of the physical properties of plant materials, the occurring dependences among many properties and the necessity of combining many branches of science within agrophysics make it necessary to utilize the scientific potential more effectively.

It also seems necessary to create a centre of scientific information in the range of agrophysics, that would keep up to date all the scientific posts, but also form a bank of all achievements, of use to plant breeders, agricultural machines constructors, mechanizers and technologists.

In connection with the above there appears the proposal of creating a permanent international working commission, that would undertake to work out coordination principles for investigating the physical properties of plant materials and to realize the sent-in proposals. It would be a way leading to the integration of means, proper direction of investigations, to the unification of methods and apparati, to the exchange of achievements and to the extention of effective international cooperation.

Address of the author

Doc. Dr Bogusław Szot, Institute of Agrophysics Polish Academy of Sciences, ul, Krakowskie Przedmieście 39, 20-076 Lublin, Poland