MECHANICAL PROPERTIES OF ROOT PLANTS

Władysław Byszewski

The present paper constitutes an introduction to a poster session concerning the mechanical properties of root plants. So its purpose is to present in a synthetic way the results of investigations carried out in this range, mainly in Poland. The discussed range of problems consists of problems from the border area between the natural and technical sciences. And in the case discussed this connection is exceptionally strong. This follows from the fact that proper methodological solutions require a deep knowledge of physics and technology as well as biology. On the other hand it is connected with a wide circle of receivers interested in the application of results of the investigations in question. They are, among others, specialists in breeding, and plant cultivation, evaluation of varieties, storage, processing and also the construction and usage of machines. The range of the present report is limited by two main points — first, the fact that the author is a biologist, and, second, that it seemed to the point to concentrate on problems that have been interpreted in different ways, and hence requiring further discussion. The pointing to them will allow to shape the discussion from which the organizers of the Conference expect help in the further direction of the so important problem. The ensuing remarks are systematized in the followig sequence:

1. The significance, purpose, and range of the investigations in question,
2. A short characterization of the papers proposed for the poster session,
3. Remarks concerning the methodology and equipment used.

THE SIGNIFICANCE, PURPOSE, AND RANGE OF THE INVESTIGATIONS IN QUESTION

Investigating of the physical, and particularly the mechanical properties of plants is strongly connected with the level of technization

of agriculture. Hence it is understandable that they are different in time. In Poland three periods can be distinguished in this range:

The first, interwar period is characterized with a low level of the technization of agriculture and at the same time with a low interest in the subject range in question. This was expressed in fragmentary investigations of the evaluation of the more important of plant properties, that directly influenced the usable value of the obtained raw materials. As an instance I can mention the works of breeders in the range of determining the geometrical features of potatoes and beets, the hardness and sometimes the breakability of sugar beet, etc. The second period lasted more or less to 1970. In this period we observe an increase of interest in the mechanical properties of root plants, mainly in the aspect of their relation to the increase of the level of mechanization. The purpose of the infrequent investigations carried out in this period was the optimization of relationships occuring between soil, plant and machine. The production systems introduced a rather short time ago were based on the knowledge of relatively simple relationships observed to take place between plant and machine. However, thay become useless as the increase of the level of technization of agriculture caused the greater and greater dependence of plant production on the physical properties of plants. The third period is characterized by a further increase of interest in the subject range in question, which was organized into systematical and coordinated investigations directed by the Institute of Agrophysics of Polish Academy of Sciences. A particularly characteristic feature of this stage of investigations is the trend to invent new prototypes of appropriate apparati and to work out proper and unified investigation methodology. The investigation of the mechanical properties of root plants is particularly important and at the same time difficult in the case of root plants. This follows from the fact that they are characterized by an exceptionally high variability within a population, and at the same time react strongly to environmental, and particularly soil conditions. To put it in a different way, in this case we deal with high variability, both individual and environmental. Moreover with root plants the agricultural crop is constituted by their underground parts, the harvesting of which is labour consuming. Thus in this case mechanization enters the scene very rapidly, often without any prior biological and organizational preparation which creates the danger of the occurence of high crop losses. The problem of the limitation of losses becomes in agriculture more and more important. The more so, that the more production means we use, and in connection with the increasing interest in the energetical balance, it is disquieting that only about 20% of the biomass produced constitutes the agricultural crop, out of which, after deducting

the losses occured during storage and processing, only about a half is actually used.

One of the more important sources of losses are the unfovourable parameters of the mechanical properties of plants, influencing the course of harvesting and storage of root plants. Hence the great importance attached to the resistance of tubers of potatoes and the beet roots to mechanical damage. In the case of root plant production there is an exceptionally unfavourable energy balance. This state of things can be to a degree improved by breeding varieties of improved mechanical properties. This concernes such properties as the resistance of roots during the heading of beets, the force necessary to remove roots from soil, the force binding the tuber with stolons, some geometrical features and particularly the positioning of tubers below a potatoe bush, which determines the amount of soil taken by the potato diggers, etc.

In the group of root plants potatoes and sugar beet are of the greatest economic importance. That is why the investigations in question are concentrated on these two species. But the range of investigations and the number of properties of interest are greater in the case of beets. This plant is cultivated mainly as a raw material for the sugar industry, which demands high qualitative standards from the received raw material, and to high a degree the demands concern the physical properties of the beet roots. Moreover beets are a two-year plant and the character of the mechanical properties of interest to us changes in the course of the development of the plant. Generally we are most interested in the determination of the variability range of the mechanical properties of the sowing material, of plants during harvest, and of beet seedlings (second year of growth of the plant). High practical importance is also presented by the properties of the raw material that are connected with its usable value and the ability of storing. The sowing material of beets is greatly varied, which follows from specific and complex build up of the beet glomus, and from the rather varied measures to which the material is subjected in the process of preparation for sowing. So in this case we should consider both the natural properties of the glomuses and those that are given to them as a result of the applied measures of preparation (calibration, preparation, areoling, etc). The introduction into practice of precision sowing machines caused the growth of interest in the geometrical properties of the glomuses and also in the parameters connected with the friction coefficients of the glomuses, and also in in the parameters connected with the coefficients of the glomus-steel friction glomus-wood friction and the interial friction, considering in this range the conditions that exist in the sowing machines, cleaning machines and during storage. With the increase of the area beets and potatoes har-

vested mechanically grows the interest in these properties, determining the possibility of the exploitation of machines used for harvesting without breaking down. These are both the mechanical and the geometrical properties of plants, connected with the work of machines used in the processing (ex. the degree of woodening of roots, hardness, that influence the course of cutting the roots in factory processes).

In all the mantioned examples it is important to level the discussed parameters and to restrict their range of variability. This follows from the way of cultivation, homogenization of environment and the breeding of new varieties (the anisopoidal varieties are characterized by higher variability). A vast majority of the problems mentioned was included in the papers sent in, that will be characterized shortly below.

A SHORT CHARACTERIZATION OF THE PAPERS PROPOSED FOR THE POSTER SESSION IN THE RANGE OF ROOT PLANTS

In the discussed group of problems seven reports were proposed; in this number four were concerned with potatoes, three with beets. The fourth beet report was concerned with thermal properties, so it was included in another problem group. While two reports concerning fruits and vegetables, because of similar methodology, were included into the problem range discussed. All the authors discussed new investigations, often still uncompleted, so the information contained in the reports could be full. The value of the reports consists in the presentation in detail of the applied methodology. Because it is not yet unified in this country the confrontation of different initiatives in this field was very valuable. Hence, analyzing the proposed reports, it seems to the point to concentrate mainly on the methodological problems. As to potatoes, the majority of investigations concern the resistance of tubers to mechanical damage, but particular authors try to solve the problem in different ways. K. Jastrzębski and J. Lewosz in their investigations of the resistance of potato to mechanical damage of tubers paid the greatest attention to investigating the cell walls of tubers. They applied a method causing pressure and mechanical damage of tubers as a result of shock with a steel ball 15 mm in diameter and 200 g in weight. It is a rapid method allowing two people to evaluate several hundred of samples per day. Differences among breeds were found, and the resistant breeds were characterized by a higher percentage of cell walls in fresh mass of whole tuber. Celulose fibers in the resistant breeds formed greater bundles, while the surface of walls in the susceptible breeds is smooth. The darkening of hit tissue is probably the effect of the freeing of the destructive gydrolitic and oxidation enzymes from organelles and cell walls, caused by the breaking of lipid films by mechanical shock. Also G. Sowa

and Z. Czerko concern themselves with methods of measurement of the resistance of tubers to mechanical damage. In this case, however, the object were not anatomical investigations, but the comparison of the damage index "W" with the results obtained at the application of the dynamic pendulum penetrometer and the static spring penetrometer. As a result of three year investigations no satisfactory corelations between the damage occred during harvesting and the indications of the penetrometers were obtained, but a high index of corelation between the indications of the static and dynamic penetrometers was established. The authors determined the influence of the more important agroecological factors on the value of the damage index, that depends to a considerable degree on the term of harveting, the type of machine used, and on the variety features. The authors suggest the necessity of undertaking further investigations on the working out of new methods for the determination of the resistance of tubers to mechanical damage. Also Z. Skorzyńska and A. Zdanowicz concerned themselves with investigating the resistance of potato to mechanical damage. In their report they discuss the problem of characterization of strain forces and the deformation of plants during the action of agricultural machines. In the investigations they used an apparatus for the determination of the resistance of agricultural crops to mechanical damage in which a potato is hit from above with a cylindrical stamp; the range of hitting is from 1 to 3.5 m/s. The recording of the changes is on the screen of two stream oscillograph, which allows for the investigation of the course of the force of deformation in time or for the recording of force in relation to deformation. It was found that the value of the specific energy of deformation is a characteristic for the particular varieties. The knowledge of the value of specific energy at a given speed can be used as a criterion for the determination of the applicability of particular varieties to mechanized harvesting. B. Bieluga in his report under the title "Determination of the degree of technical ripness of different varieties of potatoes on the basis of their physicomechanical properties" discusses the susceptibility of some varieties of potatoes to damage caused by static loading, and the determination of the reaction of tuber to dynamic loading. He applied both a static and a dynamic methods. He carried out measurements of strain under the stamp of static penetrometer, entering the potato, the deformation of potato with the stamp of static penetrometer, and the coefficient of resitution of kinetic energy. The greatest inter-variety differences were found in the first term of investigations. B. Bieluga in his report under the title "Own methods for the determination of the physico-mechanical properties of agricultural crops" described and discussed measuring equipment allowing for the determination of different phy-

sico-mechanical properties of agricultural crops. This concerns a static spring penetrometer, apparati for the measurement of skin removing force, Schob's elastometer, a dynamic penetrometer and a penaterometer for the measurement of the indexes of resistance and the influence of the speed of the shock element on the damage caused. Also K. Zdun and J. Piotrowski presented equipment and apparati for the measurement of some physical properties of potatoes. A slightly different problem was dealt with by A. Wierzejska, who investigated factors influencing the tuber-to-stolon binding force with the help of a picker for stolons, designed by the workers of the Institute of Mechanization of SGGW. The investigations carried out in the period 1973-1975 concerned 4 varieties cultivated at three levels of nitrogen fertilization. She found inter-variety differences, also the influence of vegetation conditions proved significant, while the level of fertilization and undergermination did not have any significant influence.

All the papers concerning sugar beet are characterized by the fact that they present investigations carried out on plant material coming from experiments set jointly, and in some investigations only some fragments of field experiments were utilized. It comprized four varieties sown in four localities on two levels of mineral fertilization at two terms of harvesting.

W. Nowicki, P. Banasik and P. Kołodziejczyk concern themselves with investigating the resistance of beet root to cutting and compressing, and with the process of sugar beet creep during compressing. For the determination of the visco-elastic constants for sugar beet roots the experiment of uniaxial compression was used. The investigations were carried out on one variety AJ_3, sections of root were placed under a slightly modified piston of Höppler's consistometer, measuring the course of deformations in time. The authors arrive at the conclusion that the proposed mechanical visco-elastic model is correct and that its application enables the obtaining of sufficient exactness in technical calculations.

W. Byszewski and co-researchers in their investigations investigated the geometrical and anatomical features of roots; the hardness of root was determined with Vukov's apparatus, the permeability and the basic usable properties for the determination of the relationships between them. Investigations carried out with Bieluga's penetrometer and with a dynamic penetrometer generally confirmed the results of investigations carried out with Vukov's apparatus. Investigations carried out with Schob's elastometer showed higher elasticity and resistance to root cracking, that came from fields of higher level of fertilization. Moreover measurements of the displacement, permeability, degree of damage at static and dynamic loading and of elasticity were made in the Agricultural Academy

in Lublin. Also the force with which the glomuses are bound to shoots in different agroecological conditions and at different degrees of ripness of plants were determined.

Independent from the investigations of beets and potatoes the paper group discussed included the report of J. Kozicz on the subject "Investigations of the influence of mechanical shock energy of the degree of damage of roots of vegetables" and the report of B. Bieluga and M. Bakalarz — "Comparative investigations of the physico-mechanical properties of chosen varieties of apples from the point of their applicability for mechanized harvesting". They are concerned with problems similar to those dealt with by the above enumerated papers. In the investigations of apples the authors concerned themselves with the evaluation of force necessary to break apple off from dwarf shoot and with investigating the resistance of fruit to mechanical damage. Four varieties of apples were investigated at different terms of measurements. For the investigation of the force of breaking apple off from dwarf shoot a hand operated dynamometric lever with a holder, a tensometric transformer of force with a tensometric bridge, and an indicator, was used. The resistance to damage was determined with the help of a dynamic shock apparatus and a recording system. It was found that the value of force necessary to break apple off from dwarf shoot and the resistance to dynamic damage depend on variety and the ripness of apple. The red side of fruit has a higher resistance to dynamic loading than the green side.

REMARKS CONCERNING THE METHODOLOGY AND EQUIPMENT USED

The presented review of reports from the range of the determination of the mechanical properties of root plants shows that at the present stage of investigations the most important task is to work out proper methods and the construction of appropriate apparati. This problem is extremely difficult, since it would be dangerous to impose in this range any established patterns of long term character. With the progress of investigations methodology and equipment will undoubtedly become more perfect. But I think that for the solving of some concrete problems in the nearest future it is necessary to introduce measurement methods giving a possibly compatible results and equivalent to the natural conditions of the occurence of the phenomenon we are going to investigate. At the same time it should be stressed that basically both methodology and apparati used for investigating the mechanical properties of root plants in the majority of cases do not have a specific character. This means that we deal with the same problems as in the case of investigating other plant groups. Hence future discussion will probably go in groups of essential problems and not in the division into plant groups.

Moreover many problems mentioned here, like for instance the resistance to shock, or the forces binding seeds, will be found in other investigations as well. Hence so as not to repeat myself I will give my remarks in a shortened form. It seems that investigations of the mechanical properties of root plants, as indeed any plants, should go in the following sequence and directions:

The first task is the setting up of classification of the investigated properties, and terminology. The systematization of these problems and the acceptance of an uniform terminology to a considerable degree will facilitate the further development of investigations in this range. Considering the multiplicity of the properties of interest to us, and of the species and varieties of cultivable plants it is not possible to comprise the whole of the problem in a short time. That is why in order to create proper conditions for the concentration of investigations it is necessary to set up a hierarchy of their importance, which will help the coordinator to initiate necessary investigations. We should always expect that some portion of the investigations will result from immediate demands for the clarification of difficult points in new technological processes, but we should forestall these difficuties by organizing the investigations of all the properties that can be necessary in the nearest future. It is obvious that the selection of subjects cannot be restricted to purely utilitarian matters connected with the technization of agriculture, since the clarification of many problems from this range can have a considerable cognitive significance. And despite the fact that in the initial period of investigations they will not find practical application they can be of great service in an even not too distant future. The discussed investigations should be concerned with limit values occuring in certain agroecological conditions and for particular varieties. This will allow to determine the source of variability that is to explain which of them are determined mainly by hereditary properties and which are caused by environmental variability. This will allow to show whether their optimization can take place mainly by organizing appropriate selection works or by the working out of proper systems of production. A certain basis of action in this range can be the working out of a version of catalogue of plant properties connected with the work of machines which, however, because of its character, would treat the problem in a broader way without restricting the matter to purely mechanical properties. Since the limit values of the investigated mechanical properties can be modified both by the hereditary properties of the constantly changing varieties and by the ways of cultivation, these must be materials kept up to date for strictly determined agro-ecological conditions. After the determination of the more important properties thatwe are going to investigate the de-

tailed methodology and course of action should be worked out. The greatest difficulty and problem in this range is the consideration of variability of the investigated material. I stress this specially, since some investigations carried out on limited material coming from the same agro-ecological conditions and their results do not have any greater cognitive significance.

Generally we are interested in the mechanical properties of certain populations which are usually different than those of single plants. Hence our investigations are divided into two stages: Investigations of the mechanical properties of single plants in order to find out of what order are the values of the investigated parameters, to check the equipment and to clarify some methodological points. After these introductory investigations we pass on to investigating populations, making measurements on representative sample populations. Both in a single tuber of potatoe and in a root of beet the distribution of the investigated properties can be greatly varied. That is why it is so important to determine precisely the place of the plant on which we make the measurement, or the method of taking the section of root or tuber. We should also consider the developmental variability. Many mechanical properties are subject to strong modification in the course of the development of plant. Thus the term of measurement is of considerable significance. This concerns mainly the cases when the population of plants is differentiated, matures at different times, etc.

Another problem is the extent of the sample population so that it represents as exactly as possible the values for whole population. The same concerns the number of repetitions. Another problem requiring consideration is the variability caused by agro-ecological conditions. The most adequate would be to make determinations on material coming from different conditions differentiated in a controlled way. Such a course of action is represented by some of the discussed reports, but at the same time some authors restricted themselves to making measurements on little representative samples, which, of course, considerably lowers the significance of the obtained results. Thus there are two courses of action — to confine onself to a small sample assuming that the results are true only for strictly determined conditions, and making them as exact as possible. Or else to seek rapid, mass methods, which can lead to the lowering of the precision of determinations. The choice of method depends on the objective to which the results are to be applied. In the first case we can solve some theoretical determinations. In the second we can determine the distribution and the limit values of the investigated properties, basing on broad and representative material.

The same is true in the case of equipment, in the case of carrying

out basic and methodical investigations, it is puposefull to use precision equipment, with which a single measurement can last considerably long and is made on a small section of plant. The determination of the mechanical properties of plants for the purposes of plant breeding or the evaluation of varieties requires apparati allowing for the carrying out of mass measurements on representative samples and in a short period of time, which is necessary from the point of eliminating for instance the developmental variability. Thus we must choose equipment suited for the purpose of investigations, or else look for a reasonable compromise. In the case of investigations of the mechanical properties of root plants in many cases we used succesfully the apparati worked out for cereals by the Institute of Agrophysics of Polish Academy of Sciences. And thus for example with measurements made on the beet seedlings we could use stalk intersection measuring apparatus, the recorder of grain deformation, the eletronic micropicker, the field electrodynamometer, the simulator of grain fall-out etc.

Relatively greatest number of controverssions is caused by the investigations of potatoe deformations. The authors use different methods, which makes the comparison of results difficult. In this case the differences between results obtained with methods of static pressure and with the shock method (dynamic) are greater than in the case of sugar beet. This is obvious, because potatoe, containing a lot of water, has a relatively small limit of biological liquidity, and it is strictly connected with the speed of deformation. Hence the evaluation with static methods leads to considerable differences and often varieties showning high resistance to static loading are strongly damaged in the process of harvesting. The method applied must be suited to the properties of the raw material and reproduce as exactly as possile the course of the investigated phenomenon in natural conditions. The speed of deformation of the raw material in the apparatus must be close to the speed of deformation by the working parts of machines. This concerns the case when we investigate phenomena from the range of relations between plant andmachine. It, however we are interested in deformations occured in a prism or tank we should apply other parameters. The above mentioned problems do not constitute the whole range, but it seems that they can be of help in the directing of discussion that will facilitate the proper organization of investigations from the range of the evaluation of the mechanical properties of root plants in the future.

Address of the author

Prof. Władysław Byszewski
Institute of Plant Breeding and Genetics, Agricultural University, ul. Nowoursynowska 166, 02-975 Warszawa, Poland