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AERODYNAMIC AND GEOMETRIC PROPERTIES OF AMARANTH SEEDS*

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A b s t r a c t. Geometrical properties (thickness, width and length) of individual amaranth seeds were measured by means of an optic device. The measurements allowed us to be calculated the values of seeds bearing surface for estimating aerodynamic properties. The determination of aerodynamic properties was performed using prototype apparatus adapted to suit the size of amaranth seeds. With such parameters as: dynamic pressure, seed mass and seed bearing surface basic aerodynamic properties: critical velocity, coefficient of aerodynamic resistance and coefficient of fineness were calculated. Critical velocity was found dependant on seed bearing surface, width, length and mass of the seed. With an increase of these parameters the critical velocity increased linearly and the coefficient of fineness decreased following the same formula. Both relationships were described with linear equations.

K e y w o r d s: amaranth, seeds, geometrical features, aerodynamic properties

INTRODUCTION

Already in the prehistoric times some varieties of amaranth were domesticated. There are about 60 varieties of the *Amaranthus* L. Species on the American continent. The most important of them are as follows: *Amaranthus caudatus*, *Amaranthus hypochondriacus*, *Amaranthus cruentus*.

Amaranth seed yields are very high (in Polish conditions from 1.8 to 3.5 t/ha [14]. The seeds contain 13-15% of protein, 58-68% of starch, and 3.8% of fat [8]. Amaranth protein is rich in exogenous amino acids (among others, lysine). In the amaranth seeds there is also a significant amount of iron (five times more than in wheat), calcium, vitamins from the B group, as well as vitamin A, E, and C. Also the fat content and the content of indispensable unsaturated fatty acids is higher than in traditional cereals. Oil made from the seeds contains skwalen - a component used in cosmetics and electronics (for moisturising computer discs). Amaranth starch grains are very small and can be used in the pharmaceutical and food industry [12].

In Poland, first studies on amaranth started in 1989. They concentrated on the physiology, yielding, acclimatisation and breeding of this new, valuable plant. It is possible to create Polish varieties on the basis of the amaranth breeding collection from the whole world. All the trials and studies aim at obtain new forms with higher proliferacy and better seed quality [14].

In the Garden of Medicinal Plants in Wrocław love-lies-bleeding has been sown for many years and has been well documented [12]. Studies on the influence of sowing on the plants' growth, development, and yield have also been carried out by Gontarczyk and Aufhammer [7]. Nalborczyk - the father of amaranth in Poland, has also studied, among other things, its photosynthesis and biomass and nutritive element build up [13].

Since the breeding of amaranth has already started in Poland, harvesting machinery is becoming very important. Studies on the size of losses and contamination of amaranth seeds in relation to moisture level of the threshed material, rotation velocity of the drum, and type of concave (of the thresher) have been carried out [2].

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Amaranth should become a source of healthy food, rich in protein, exogenous amino acids, unsaturated fatty acids, vitamins and mineral salts. Trials on using amaranth flour for bakery products showed that good effects can be achieved [6,10]. Experience with amaranth grinding and flaking proved that it is possible to grind and flake amaranth seeds with roller mills widely used in mills, and that both flour and flakes are a rich source of nutritious cellulose with good smell and taste [5].

Good baking qualities of amaranth suggested also good fermentation properties. The studies carried out showed that an addition of amaranth favourably influences fermentation speed and quantity of alcohol in rye mash [3]. The same research team also compared the quality of raw spirit made from rye, triticale, and amaranth with the following conclusions:
- amaranth mash ferments the quickest, so fermentation time can be shortened;
- the amount of alcohol obtained from amaranths and triticale is far higher than from rye [4].

Amaranth is also becoming increasingly important in animal feeding. It can be fed as green fodder, dried hay, silage, briquettes, and very valuable feed concentrates [16]. There are also some attempts to utilise amaranth seeds as a supplementing plant for fallow-deer fodder [9].

Extrusion results in highly palatable fodder mixes. Studies on the extrusion of barley middling with 10 to 50% addition of amaranth seeds proved that with an increase in the percentage inclusion of amaranth seeds in the mixture the maximum expansion values decreased and the level of working pressure increased [11].

The way animals are fed can influences human nutrition. Experience has shown that amaranth seeds used in the breeding of laying hens result in positive changes in the contents of indispensable unsaturated fatty acids in yolk [15].

Amaranth herbs are a source of mineral salts, vitamins and phenylacids that are also used in herbal treatment [18].

In all the areas just mentioned it is necessary to learn about the physical features of this plant. Nalborczyk [14] quotes properties of the seeds as given by some foreign researchers. Seed size ranges from 0.9 to 1.7 mm (diameter of 1.5 to 2.14 mm can be achieved as a result of breeding programmes). The weight of 1000 seeds is from 0.7 to 0.9 g. Wild and vegetable forms of amaranth have dark seeds, whereas those grown for seeds are light in colour [14]. In the Polish soil and climatic conditions we can obtain seeds with specific physical characteristics that require determination.

Results obtained in the Institute of Agrophysics of the Polish Academy of Sciences showed, without any doubt, high variability of physical parameters of amaranth seeds in relation to their moisture content during ripening and immediately after harvest [21]. It is true both for individual seeds (geometrical features, surface roughness, mechanical resistance) and parameters of the seed mass (porosity, bulk density, the angle of slide and repose).

In the studies carried out by the present authors, geometrical features (such as: width and length), seed bearing surface, and basic aerodynamic features (such as: critical velocity, coefficient of aerodynamic resistance, and fineness ratio) were determined.

METHODS

Geometrical features

By means of an optic device the surface of the orthogonal seed projection was represented with 29.7 magnification. The contour of the seed surface obtained allowed for the calculation of the values of bearing surface S and for the determination of the seed length c and width b. In order to determine the degree of approach of the bearing surface to the wheel surface, the ratio between seed length and its width was calculated.

Aerodynamic features

In the vertical stream of air (Fig. 1) the dynamic pressure that was holding the seed in a state of balance was measured. With such known parameters as: dynamic pressure, seed mass, and seed bearing surface, it is possible to calculate basic aerodynamic features:

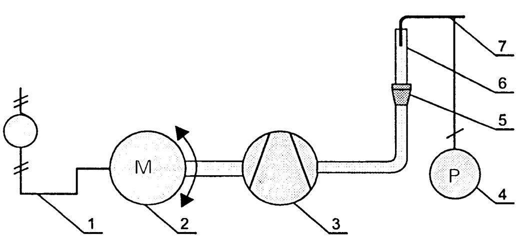


Fig. 1. Schema of the stand for determination of the aerodynamic properties: 1 - autotransformer, 2 - electric motor, 3 - fan, 4 - compensating micromanometre, 5 - charging mechanism, 6 - glass tube, 7 - Pitott tube.

$$v_k = (2/\rho \ P_{\rm dyn} \ g)^{1/2} \ [\text{m/s}] \qquad (1)$$

where v_k - critical velocity, ρ - air density, $P_{\rm dyn}$ - dynamic pressure, g - acceleration of gravity;

$$k_x = 2\ mg/S\rho v_k^2 \ [-] \qquad (2)$$

where k_x - coefficient of aerodynamic resistance, m - seed mass, S - seed bearing surface;

$$k_o = g/v_k \quad [1/\text{m}] \qquad (3)$$

where k_o - coefficient of fineness [1/m].

After mathematical elaboration the influence of geometrical features on the aerodynamic properties of amaranth seeds were determined.

RESULTS

Figure 2 presents an example of the studied amaranth seed contour. The smallest measured value of the bearing surface was S_{min} = 0.81

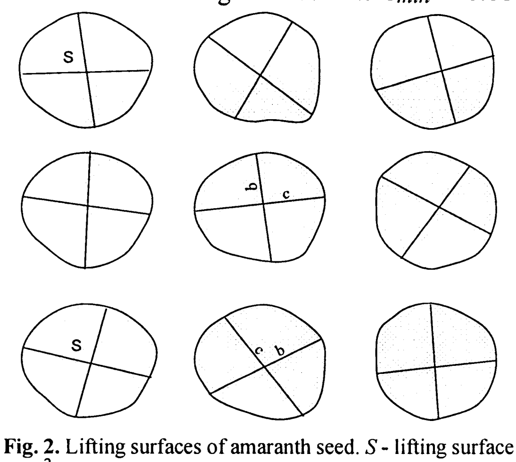


Fig. 2. Lifting surfaces of amaranth seed. S - lifting surface [mm^2], c - length [mm], b - width [mm].

mm^2, and the biggest was S_{max} = 1.47 mm^2, the mean value of this surface is S_{mean} = 1.22 mm^2. In the range from S = 1.2 mm^2 to S = 1.3 mm^2 there are 29% of all the studied seeds, and in the range from S = 1 mm^2 to S = 1.4 mm^2 there are as many as 82% of all the seeds (Fig. 3). Figure 3 illustrates the distribution of seeds length, width, relation between length and width, mass, critical speed, dray and fineness coefficients.

Amaranth seed length ranges from c_{min} = 1 mm to c_{max} = 1.50 mm. The mean seed length was c_{mean} = 1.34 mm. About 72% of the seeds were of the mean length (range from 1.2 mm to 1.4 mm).

Amaranth seed width is a little smaller and ranges from b_{min} = 0.9 mm to b_{max} = 1.35 mm. The mean width is b_{mean} = 1.19 mm. About 92% of the seed show that width (range from b = 1.0 mm to b = 1.3 mm).

Amaranth seeds are near to spherical in their shape, as proved by the ratio of their length and width c/b. This is from 1.0 to 1.25, with a mean value of c/b = 1.11.

The mean weight of a single seed is m_{mean} = 0.807 mg, and most of the studied seeds showed this weight. The smallest seed had a weight of m_{min} = 0.456 mg, and the biggest m_{max} = 1.112 mg.

The most important aerodynamic feature is critical velocity. Its extreme values are as follows: $v_{k\text{-}min}$ = 3.10 m/s and $v_{k\text{-}max}$ = 4.25 m/s. The mean critical velocity was $v_{k\text{-}mean}$ = 3.69 m/s. The value of critical velocity is quite high for such small seeds. It proves that the seeds are very spherical and suggests a smooth surface.

The coefficient of aerodynamic resistance is, respectively: $k_{x\text{-}min}$ = 0.6143 to $k_{x\text{-}max}$= 1.0245, and with $k_{x\text{-}mean}$ = 0.8137.

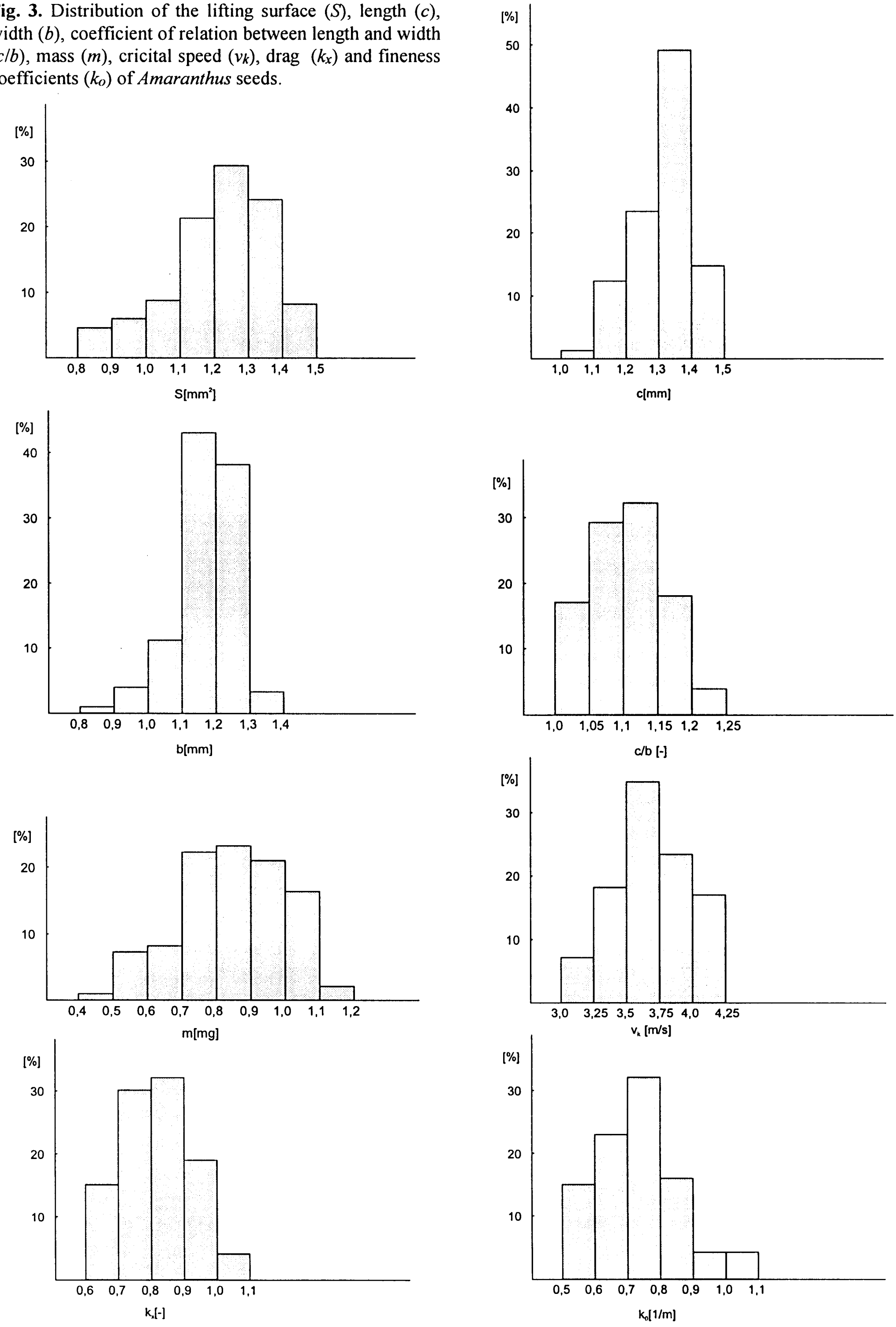
The coefficient of fineness is $k_{o\text{-}min}$ = 0.5432 to $k_{o\text{-}max}$ = 1.0208, and $k_{o\text{-}mean}$ = 0.7296. Critical velocity vk depends on the bearing surface S, length c, and weight m. The relation is described by the following linear equations (Fig. 4):

$$v_k = 2.025 + 1.366\ S,$$

$$v_k = 1.332 + 1.764\ c,$$

$$v_k = 2.585 + 1.309\ m.$$

Fig. 3. Distribution of the lifting surface (S), length (c), width (b), coefficient of relation between length and width (c/b), mass (m), cricital speed (v_k), drag (k_x) and fineness coefficients (k_o) of *Amaranthus* seeds.



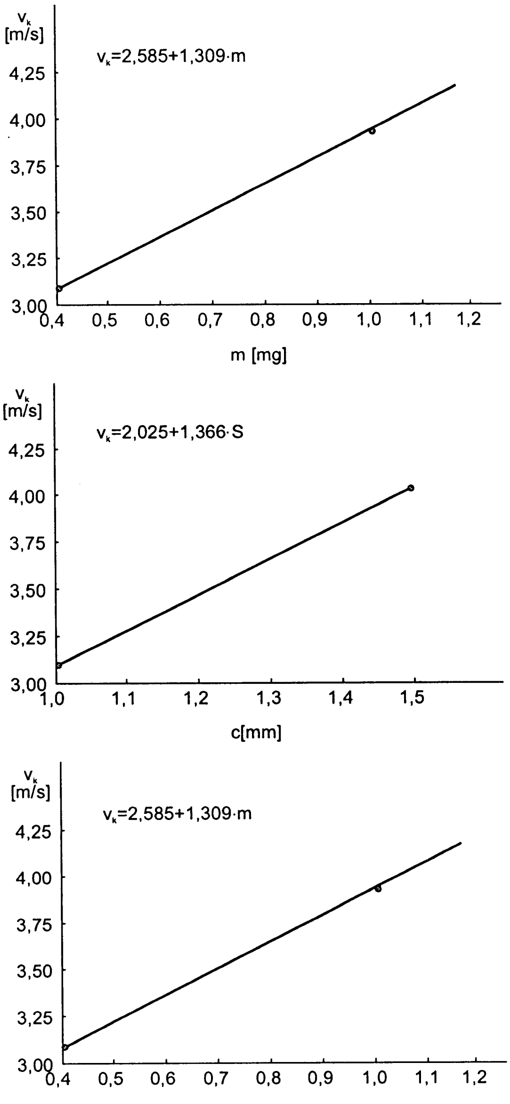


Fig. 4. Critical speed (v_k) related to lifting surface (S), length (c) and mass (m).

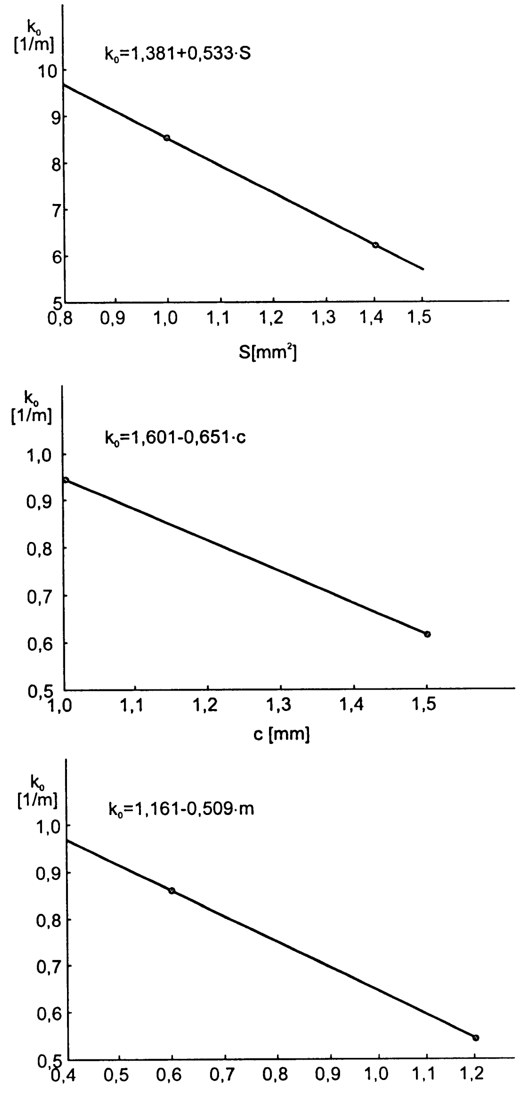


Fig. 5. Fineness coefficient (k_o) related to lifting surface (S), length (c) and mass (m).

The coefficient of fineness k_o is also linearly dependent on the bearing surface S, length c and weight m. The formulas below describe these relations (Fig. 5):

$$k_o = 1.381 - 0.533\ S,$$

$$k_o = 1.601 - 0.651\ c,$$

$$k_o = 1.161 - 0.509\ m.$$

CONCLUSIONS

Amaranth seeds can be compared to balls with a diameter of 1.34 mm.

Basic aerodynamic parameters of seeds depend on such seed parameters as: bearing surface S, length c, and mass m. With an increase of these parameters the critical velocity v_k increases linearly, and the coefficient of fineness k_o decreases according to the same formula (y=a + b x).

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