The impact of size and shape of particles of undergrowth and herbs mixtures on aerodynamic properties

Wpływ wielkości i kształtu cząsteczek mieszanin runa leśnego i ziół na właściwości aerodynamiczne

Marian PANASIEWICZ*, Paweł SOBCZAK, Kazimierz ZAWIŚLAK, Elżbieta KUSIŃSKA, Jacek MAZUR and Rafał NADULSKI

[1]University of Life Sciences in Lublin, ul. Doswiadczalna 44, 20-236 Lublin, Poland, *marian.panasiewicz@up.lublin.pl

Abstract

The impact of the size and shape of a selected group of herbs (dried juniper berries – *Juniperus communis*, dry blueberries – *Vaccinium myrtillus*, petals of cornflower – *Centaurea cyanus*) on the value of the volatility coefficient, the coefficient of sphericity and the critical speed was analysed in the presented research. A laboratory anemometer to measure the speed of air was used. The determination of the volatility coefficient of particular size fractions was conducted on the basis of critical speed values, calculated as an average established after five measurements. The established aerodynamic properties of particular mixtures allow the determination and the assessment of differences among fractions of valuable resources and different impurities. The presented data might constitute a basis to determine the scope of differences among them and establish interrelations which allow the application of proper parameters for the pneumatic separation process in practice.

Keywords: aerometric properties, herbs, pneumatic separation

Streszczenie

W pracy przedstawiono analizę wpływu wielkości i kształtu wybranej grupy ziół (wysuszone szyszkojagody jałowca, suche jagody borówki czernicy, płatki chabru bławatka) na wartość współczynnika lotności, współczynnika sferyczności i prędkości krytycznej. Do pomiaru prędkości powietrza zastosowano anemometr laboratoryjny. Wyznaczanie współczynnika lotności poszczególnych frakcji wymiarowych realizowano w oparciu o wartości prędkości krytycznej, obliczonej jako średnia z pięciu pomiarów. Wyznaczone właściwości aerodynamiczne poszczególnych mieszanin pozwalają ustalić i ocenić różnice pomiędzy frakcjami cennymi surowców i różnymi zanieczyszczeniami. Zestawione dane mogą być podstawą do określenia zakresu różnic między nimi i ustalenia wzajemnych zależności umożliwiających zastosowanie w praktyce odpowiednich parametrów procesu pneumoseparacji.

Streszczenie szczegółowe

Praca dotyczy określenia i analizy wpływu wielkości i kształtu wybranej grupy ziół i runa leśnego (wysuszone szyszkojagody jałowca, suche jagody borówki czernicy, płatki chabru bławatka) na zmianę wartości współczynnika lotności oraz pozostałych właściwości aerodynamicznych. Przebieg i charakter badań ukierunkowano pod kątem wyznaczenia wzajemnych zależności i korelacji zachodzących pomiędzy wybranymi cechami badanych ziół (wielkość i kształt), a zakresem zmian wartości ich współczynnika lotności (k_o), współczynnika sferyczności i prędkości krytycznej. Ponadto, w oparciu o studia bibliograficzne i przeprowadzone badania dokonano analizy wybranych właściwości fizycznych i innych czynników wpływających na wartość współczynnika lotności i pozostałych parametrów charakteryzujących właściwości aerodynamiczne badanych materiałów. Określanie właściwości aerodynamicznych poszczególnych składników mieszanin runa leśnego i ziół poprzedzone zostało ich podziałem na frakcje wymiarowe. W składzie poszczególnych frakcji, z których większość stanowiły różne zanieczyszczenia i odpady nieużyteczne, wyodrębniono materiał podstawowy, który stanowił najcenniejszą część obrabianego runa leśnego i oczyszczanych ziół. Wykorzystując zróżnicowanie w zakresie wymiarów i kształtu cząsteczek poszczególnych frakcji określano charakterystyki aerodynamiczne każdej z nich. Wyznaczone właściwości aerodynamiczne cząsteczek poszczególnych frakcji badanych mieszanin charakteryzują się dużą zmiennością, przy czym zróżnicowanie to wynika głównie z wielkości i masy tych cząsteczek. Z pośród badanych cech aerodynamicznych, najbardziej miarodajnym wskaźnikiem charakteryzującym właściwości fizyczne, ważne przy rozdziale mieszanin (czyszczeniu i sortowaniu) na frakcje jest prędkość krytyczna V_k. Najmniejsze wartości współczynnika lotności (k_o) odnotowano dla cząsteczek mieszanin ziarnistych o największym wymiarze i jednocześnie mało opływowym kształcie do których zaliczamy między innymi nasiona jałowca i jagody. Największe jego wartości odnotowano dla cząsteczek będących zanieczyszczeniami.

Introduction

The continuous increase in the production of cereal, leguminous seeds, oilseeds and herbs makes it necessary to seek for new methods of purification and segregation of grain mixtures as well as modernisation and construction of modern, more efficient segregating-purifying machines. The designation of these machines for particular operations which prepare sowing material or raw seed material for processing depends on numerous factors, which include physical properties of grain material, the degree of purification precision, as well as the capacity of a machine or a processing line. At the same time, the machines are supposed to achieve a high level of segregation and purification precision, both optimal and efficient capacity, the possibility to adjust technical-technological parameters in a wide range, and a low level of noise [Grochowicz 1994, Kośmicki et al. 1993, Horabik 2001].

In case of the process of pneumatic separation of grain mixtures aerodynamic properties of such mixtures are used as the basic separation feature [Nalbandi et al. 2010]. These properties, for both seeds of domesticated plants and weeds, are characterised by three indices, i.e. the critical speed of lifting, the coefficient of aerodynamic resistance, and the coefficient of volatility [Frączek and Reguła 2012].

At the same time, the value which is the most characteristic and reflects the above-mentioned properties is the critical speed of lifting [Lorestani et al. 2012, Grochowicz and Panasiewicz 1997, Grochowicz 1994, Sobczak et al. 2011]. The critical speed is defined as the speed of a vertical stream of air which allows to maintain a grain, a seed or a particle, which constitutes an element of impurities, suspended in the air, and very often the critical speed is used as their main separation feature. In turn, the coefficient of volatility characterises the ability of a grain or seed to resist a stream of air with a particular speed of flow [Tylek 2011, Kaliniewicz et al. 2012]. For different ingredients of a mixture the values of the speed of lifting fluctuate in a wide range because it is related to a variable physical size of particles and their alignment in the stream of air (different areas of the particle plan) [Kaliniewicz 2013, Jurga 1997]. A general rule underlying pneumatic separation consists in the use of differences in the behaviour of particles under particular conditions in a flowing stream of air. The mass of particular particles is a significant property which impacts the value of the critical speed of lifting and the remaining indices. [Grochowicz 1994, Kaliniewicz 2013, Dmitrewski et al. 1981, Wierzbicki and Jadwisieńczak 2003, Zawiślak et al. 2013].

The aim of this study was to determine and analyse the impact of the size and shape of a selected group of herbs (dried juniper berries – *Juniperus communis*, dry whortleberries – *Vaccinium myrtillus*, petals of cornflower – *Centaurea cyanus*) on the value of the volatility coefficient and the remaining aerodynamic properties. The course and the character of these tests were focused in a way to determine interrelations which take place among the selected properties of tested herbs (size and shape), and the scope of changes of the volatility coefficient values (k_0), the coefficient of sphericity and the critical speed.

The scope of the study includes the following issues:

- the study of field literature which relates to the subject matter of pneumatic separation of herbs, especially taking into account the volatility coefficient,
- the analysis of physical properties and other factors which influence the value of the volatility coefficient.

Materials and methods

The research material constituted dried mixtures of juniper berries, blueberries and cornflower petals harvested in their natural state with the use of pneumatic machines. The resources come from Przedsiębiorstwo Rolno – Spożywcze [agricultural and food company] "Jan Kania" in Częstochowa. The mixtures apart from the desired fractions, such as juniper berries, dried whortleberries and dry cornflower petals, contained various organic and inorganic impurities, for example: juniper needles, leaves, small parts of stems, small shingles, sand, etc. In case of the mixture of juniper fruit only biological impurities were observed, i.e. parts of damaged fruit, thicker needles and parts of twigs and smaller dust impurities which were probably created during the process of drying and storing. The cornflower mixture additionally included seeds, parts of stems and cereal. The most polluted were fruit and whortleberries leaves, in which a big amount of dried complete and broken leaves, broken stems and small shingles with sizes similar to dried blueberries was found (fig 1).
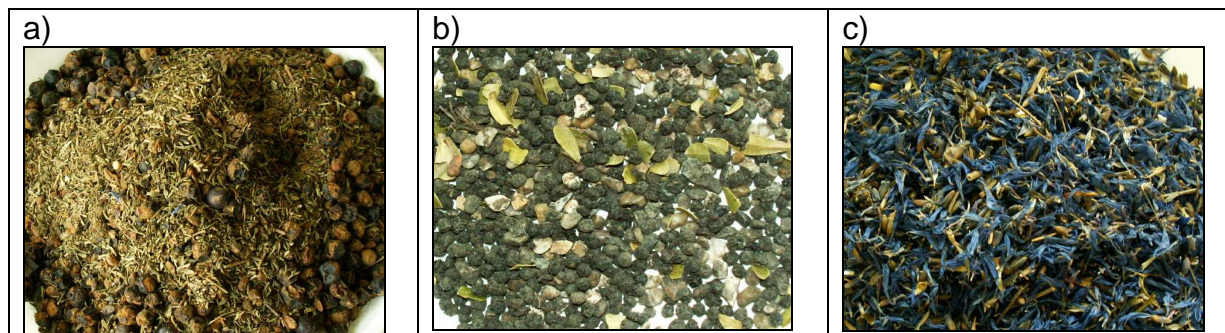
Fig. 1. Mixtures of herbs used for research: a) mixture of dried juniper berries, b) mixture of dry whortleberries, c) mixture of cornflowers.
Rys. 1. Mieszaniny ziół wykorzystane do badań: a) mieszanina wysuszonych szyszkojagód jałowca, b) mieszanina suchych owoców borówki czernicy, c) wysuszona mieszanina chabru bławatka.

The first stage of the research involved the division of particular mixtures into size fractions (table 1).

Table. 1. Data presenting sizes of sieves' apertures which were used to divide mixtures into size fractions
Tab. 1. Zestawienie danych dotyczących wymiarów otworów sit zastosowanych do podziału mieszanin na frakcje wymiarowe

Type of mixture and fraction sizes Rodzaj mieszaniny i wymiary frakcji		
Mixture of juniper berries Mieszanina szyszkojagód jałowca	Mixture of whortleberries Mieszanina borówki czernicy	Mixture of cornflowers Mieszanina chabru bławatka
Sizes of sieves' apertures Wymiary otworów sit		
5 mm – seeds (class I) 5 mm – nasiona (gat. I)	5 mm – thick impurities (shingles, parts of twigs) 5 mm – zanieczyszczenia grube (kamyki, cząstki łodyżek)	4 mm – thick impurities (cornflower seeds) 4 mm – zanieczyszczenia grube (nasionka chabru)
4 mm - seeds (class II) 4 mm - nasiona (gat. II)	4 mm – average size impurities (shingles, leaves) 4 mm - zanieczyszczenia średnie (kamyki, listki)	3.15 mm – petals (class I) 3,15 mm – płatki (gat. I)
3.15 mm – *seeds (class III)* 3,15 mm – nasiona (gat. III)	3,15 mm – berries (class I) 3,15 mm – jagody (gat.I)	2 mm – petals (class II) 2 mm – płatki (gat. II)
2 mm – thick impurities 2 mm – zanieczyszczenia grube	2 mm - berries (class II) 2 mm - jagody (gat.II)	1 mm – husk impurities 1 mm - zanieczyszczenia w postaci łusek
1 mm – light impurities 1 mm – zanieczyszczenia drobne	1 mm – light impurities 1 mm – zanieczyszczenia lekkie	0.5 mm - very light impurities 0,5 mm - zanieczyszczenia bardzo lekkie
0.5 mm – very light impurities 0,5 mm – zanieczyszczenia bardzo lekkie	0.5 mm – very light impurities 0,5 mm – zanieczyszczenia bardzo lekkie	Below 0.5 mm - dust impurities poniżej 0,5 mm - zanieczyszczenia pyliste
Below 0.5 mm – dust impurities Poniżej 0,5 mm – zanieczyszczenia pyliste	Below 0.5 mm – dust impurities Poniżej 0,5 mm – zanieczyszczenia pyliste	

The division into size fractions was carried out with the use of two sets of research stands, i.e. a laboratory sieve separator type SZ-1 equipped with a set of sieves with oval apertures with a reciprocating drive, and a laboratory sieve shaker RETSCH AS200 with adjustable acceleration caused by adjusting the amplitude of vibrations. The particle size distribution was determined according to the standard (PN-89/R-

64798 Feed - Determination of fragmentation) in which 100 g of the sample was sieved through a sieve set using a 2mm vibration amplitude and duration of screening equal to 4 minutes.

The second stage of the research involved the process of pneumatic separation in a vertical stream of air in which critical speed was determined, after which the remaining aerodynamic properties of particles of particular size fractions of mixtures were determined.

The measurement and determination of selected properties were conducted on a laboratory stand which allows smooth regulation of the process parameters (fig. 2).
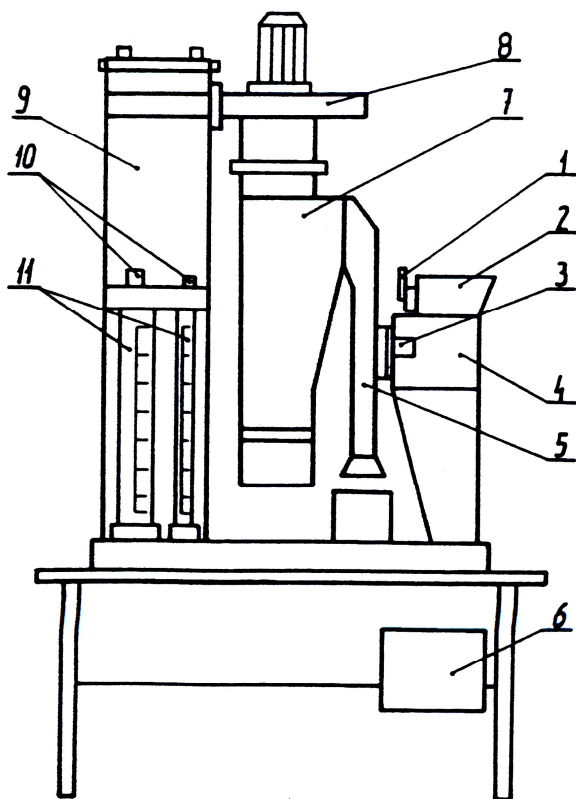

Fig 2. The laboratory stand used for the determination of aerodynamic properties of grain mixtures
1 - aperture metering, 2 - hopper, 3 - speculum, 4 - a vibrating device, 5 - channel pre-separation, 6 - control, 7 - separating chamber, 8 - fan, 9 - main compartment separator, 10 - air flow regulators , 11 - rotameters and scales read the aerodynamic properties
Rys.2. Stanowisko badawcze do wyznaczania właściwości aerodynamicznych mieszanin ziarnistych
1 - przesłona dozująca, 2 – kosz zasypowy, 3 – wziernik, 4 – urządzenie wibracyjne, 5 – kanał wstępnej separacji, 6 – tablica sterująca, 7 – komora separująca, 8 – wentylator, 9 – główna komora oddzielacza, 10 – regulatory wydatku powietrza, 11 – rotametry i skale odczytu właściwości aerodynamicznych.

The measurements of aerodynamic properties of grain particles of biological origin were conducted with the following assumptions:

- the principle for measuring the critical speed is based on capturing the moment when a particle is suspended at a given speed of the vertical stream of air,
- the range of the airflow is from 0.2 to 40 m·s^{-1},
- the flow in the section where the stream was measured was characterised by Reynolds number bigger than 8000 (to secure equal distribution of the speed of air in a cross section of an air duct).

A laboratory anemometer, which was not an integral part of the laboratory stand, was used to measure the speed of air. The determination of the volatility coefficient of particular size fractions was conducted on the basis of critical speed values, calculated as an average established after five measurements. In order to calculate the speed values an equation for the continuity of flow was used.

$$Q_v = F \cdot v_{air} \qquad (1)$$

where: Q_v - air volume expense [$m^3 \cdot s^{-1}$],

F- area of the air duct in which the separation is carried out [m^2].

From the above equation an equation for the critical speed can be achieved after a transformation :

$$v_k = \frac{Q_v}{F} \qquad (2)$$

where: Q_v - value of air indicated by the anemometer,

On the basis of the calculated critical speed in the following form:

$$v_k = \sqrt{\frac{g}{k_o}} \qquad ....(3)$$

the volatility coefficient was determined k_o, from the equation:

$$k_O = \frac{g}{(v_k)^2} \qquad (4)$$

where: v_k - critical speed,

g – gravitational acceleration, 9.81 [$m \cdot s^{-2}$],

k_o - volatility coefficient.

The results obtained for particular stages of the experiment were subjected to statistical analysis that made possible to obtain the object's function (parameters), i.e. a dependence that approximates the measurement results. It included general statistical procedures associated with the evaluation of mean values, errors, and standard deviations. The research was conducted in 10 replicates. All statistical computations were made by applying standard procedures using Statistica software package, with the significance level of $\alpha = 0.05$.

Results and discussion

The determination of aerodynamic properties of particular ingredients of mixtures of undergrowth and herbs was preceded by their separation into size fractions. In the composition of particular fractions, the majority of which constituted different impurities and useless waste, the basic material was separated, which was the most valuable part of the processed undergrowth and purified herbs. Aerodynamic

characteristics were determined for each fraction (table 2, 3 and 4), using the differentiation within the scope of sizes and shapes of particles in particular fractions.

Table. 2. Aerodynamic characteristics of selected fractions of herbs and undergrowth mixtures – mixture of juniper berries
Tab. 2. Aerodynamiczne charakterystyki wybranych frakcji mieszanin ziół i runa leśnego - mieszanina szyszkojagód jałowca

Mixture fractions (sizes of sieves' apertures) Frakcje mieszaniny (wymiary otworów sit)	Range of critical speed V_k [m·s^{-1}] Zakres prędkości krytycznej V_k [m·s^{-1}]	Coefficient Współczynnik Aerodynamic resistance k Oporu aerodynamicznego k	Volatility k_o Lotności k_o
φ-5 mm; seeds (class I) φ-5 mm; nasiona (gat. I)	17.50 ±1.2	0.229	0.0320
φ-4 mm; seeds (class II) φ-4 mm; nasiona (gat. II)	13.20±1.35	0.188	0.0530
φ-3.15 mm; *seeds (class III)* φ-3,15 mm; *nasiona (gat. III)*	10.80±1.1	0.272	0.0841
φ-2 mm; thick impurities φ-2 mm; zanieczyszczenia grube	9.90±0.96	0.222	0.1001
φ-1 mm; small impurities φ-1 mm; zanieczyszczenia drobne	3.90±0.56	0.096	0.6449
φ-0,5 mm; very light impurities φ-0,5 mm; zanieczyszczenia bardzo lekkie	3.71±0.48	0.062	0.7165
Below 0.5 mm; dust impurities Poniżej 0,5 mm; zanieczyszczenia pyliste	3.43±0.47	0.022	0.8341

In case of the juniper mixture, in which the most valuable material was its dried fruit, a big difference between the value of the critical speed of the basic material, impurities and waste was recorded. For example, the critical speed for class I juniper seeds was 17.5 m·s^{-1}, whereas the critical speed of small, light and dust impurities was 3-4 m·s^{-1}, which from the point of view of separation of valuable fractions is a positive phenomenon which conditions an efficient process of pneumatic separation [Frączek et al. 2012]. Slightly smaller differences between the basic material and impurities were recorded in case of the coefficient of aerodynamic resistance k. It

proves similar properties of particles (shape, size) of these fractions in relation to resistance to a vertical stream of air.

The separation and purification of blueberries in a stream of air was more difficult. This mixture was polluted with different sizes and masses of shingles and other waste. It proves high importance of the value of the critical speed in the fraction of thick impurities (shingles) and dried berries (class I), which value fluctuates within the range 12 -24 m·s^{-1} (table 3). Very slight differences were also recorded in case of two other determined coefficients k and k_o, which considerably hindered the separation of both thick and light impurities [Kaliniewicz et al. 2012].

Table. 3. Aerodynamic characteristics of selected fractions of herbs and undergrowth mixtures – mixture of whortleberry
Tab. 3. Aerodynamiczne charakterystyki wybranych frakcji mieszanin ziół i runa leśnego - mieszanina borówki czernicy

Mixture fractions (sizes of sieves' apertures) Frakcje mieszaniny (wymiary otworów sit)	Range of critical speed V_k [m·s^{-1}] Zakres prędkości krytycznej V_k [m·s^{-1}]	*Coefficient* Współczynnik	
		Aerodynamic resistance k Oporu aerodynamicznego k	Volatility k_o Lotności k_o
φ-5 mm; thick impurities (shingles , parts of twigs) φ-5 mm; zanieczyszczenia grube (kamyki, cząstki łodyżek)	24.60±2.14	0.744	0.0162
φ-4 mm; berries (class I) φ-4 mm; jagody (gat.I)	12.01±1.25	0.167	0.1211
φ-3.15 mm; berries (class II) φ-3,15 mm; jagody (gat.II)	7.84±1.1	0.156	0.1596
φ-2 mm; average size impurities (shingles , leaves) φ-2 mm; zanieczyszczenia średnie (kamyki, listki)	6.67±0.96	0.147	0.2205
φ-1 mm; light impurities φ-1 mm; zanieczyszczenia lekkie	4.38±0.51	0.102	0.5114
φ-0.5 mm; very light impurities φ-0,5 mm; zanieczyszczenia bardzo lekkie	3.98±0.36	0.100	0.6437
Below 0,5 mm – dust impurities Poniżej 0,5 mm – zanieczyszczenia pyliste	3.66	0.078	0.7326

In case of separation and purification of cornflower petals, particles which were present in all fractions were characterised by very similar values of all three aerodynamic properties V_k, k and k_o (table 4). Small differences among these parameters practically make it impossible to efficiently separate the most valuable fractions of petals (class I and II) [Nalbandi et al. 2010].

Table 4. Aerodynamic characteristics of selected fractions of herbs and undergrowth mixtures – mixture of cornflower

Tab. 4. Aerodynamiczne charakterystyki wybranych frakcji mieszanin ziół i runa leśnego - mieszanina chabru bławatka

| Mixture fractions (sizes of sieves' apertures) Frakcje mieszaniny (wymiary otworów sit)	Range of critical speed V_k [m·s^{-1}] Zakres prędkości krytycznej V_k [m·s^{-1}]	Coefficient Współczynnik Aerodynamic resistance k Oporu aerodynamicznego k	Volatility k_o Lotności k_o
φ-4 mm; thick impurities (cornflower seeds) φ-4 mm; zanieczyszczenia grube (nasionka chabru)	6.08±0.96	0.149	0.2654
φ-3.15 mm; petals (class I) φ-3,15 mm; płatki (gat. I)	5.32±0.68	0.139	0.3466
φ-2 mm; petals (class II) φ-2 mm; płatki (gat. II)	4.56±0.55	0.124	0.4718
φ-1 mm; husk impurities φ-1 mm; zanieczyszczenia w postaci łusek	4.02±0.36	0.116	0.6070
φ-0,5 mm; very light impurities φ-0,5 mm; zanieczyszczenia bardzo lekkie	3.22±0.39	0.099	0.9469
Below 0,5 mm; dust impurities poniżej 0,5 mm; zanieczyszczenia pyliste	3.16±0.29	0.095	0.9801

a)

b)

c)
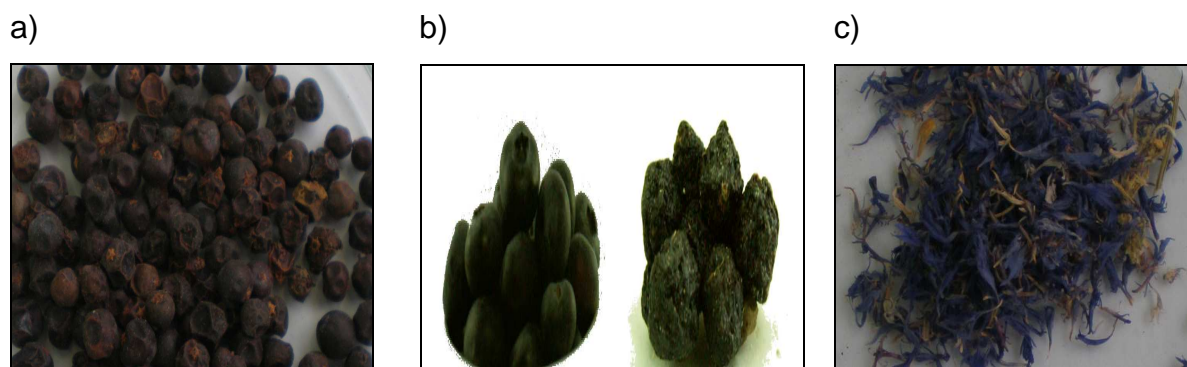
Fig. 3. Separated and purified valuable fractions of undergrowth and herbs:
a) dried juniper berries, b) dry whortleberries , c) dried cornflower petals.
Rys. 3. Wydzielone i oczyszczone cenne frakcje runa leśnego i ziół:
a) wysuszone szyszkojagody jałowca, b) suche owoce borówki czernicy, c) wysuszone płatki chabru bławatka

The established aerodynamic properties of particular mixtures allow the determination and the assessment of differences among fractions of valuable resources and different impurities. The presented data might constitute a basis to determine the scope of differences among them and establish interrelations which allow the application of proper parameters for the pneumatic separation process in practice.

Conclusions

1. The determined aerodynamic properties of particles of particular fractions of tested mixtures are characterised by high changeability, while the said differentiation mainly results from the size and mass of these particles.
2. The most reliable indicator, among tested aerodynamic properties, which characterises physical properties important while separating mixtures into fractions (purification and segregation) is the critical speed V_k.
3. The shape, size and mass of particles have a crucial impact on the values of the volatility coefficient.
4. The lowest values of the volatility coefficient were recorded for particles of grain mixtures with the biggest size and, at the same time, the least aerodynamic shape, which, among others, include juniper seeds and berries. The highest values of the volatility coefficient were recorded for particles which constituted impurities. Exemplary values for this parameter for the fraction φ-0.5 mm (very light impurities) fluctuated within the range from 0.6437 to 0.9469.
5. In case of fractions of the basic material (juniper berries, dried whortleberries and cornflower petals), the values of the volatility coefficient were 0.0320, 0.1211 and 0.3466 respectively.
6. The optimal cleaning performance and separation of herbs and undergrowth conducted at various research stands from a practical point of view was evaluated around 40% for a fraction of the base material of juniper berries, for dried fruit berries from 52 to 60% and 86% for cornflower petals.

7. The results represent an invaluable practical information and scope of the applicable technical and technological parameters possible and indicated for use in herbal plants where the processes are carried out the preparation and processing of different groups of raw herbs and undergrowth. The most important factors influenced for the effectiveness of cleaning and separation of basic fractions were physical properties, parameters and conditions of screening, the type of sieves and the shape and size of their holes in the case of industrial factory. This also applies the cleaning and separation of other groups of culinary herbs and supplements.

Acknowledgements

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