EFICÁCIA DA SECAGEM POR SORÇÃO DE SEMENTES DE SOJA E TRATAMENTO PRÉ-COLHEITA COM DESSICANTES COMO UMA ABORDAGEM ABRANGENTE**EFFICACY OF SOYBEAN SEEDS SORPTION DRYING AND PREHARVEST TREATMENT WITH DESICCANTS AS A COMPREHENSIVE APPROACH****ЭФФЕКТИВНОСТЬ СОРЕБЦИОННОЙ СУШКИ СЕМЯН СОИ И ПРЕДУБОРОЧНОЙ ОБРАБОТКИ ДЕСИКАНТАМИ КАК КОМПЛЕКСНЫЙ ПОДХОД**

SERIKKYZY, Mira^{1*}; AVDEENKO, Aleksei²; GOULY, Yoro Ella³; TYURIN, Igor⁴; STEPANOVA, Diana⁵

¹ Almaty Technological University, Department of Food Safety and Quality. Kazakhstan

² Don state agrarian University, Department of Agriculture, and storage technologies for crop products. Russia

³ RUDN University, Department of Management. Russia

⁴ Saratov State Agrarian University named after N. I. Vavilov, Department of Technical Support of Agro-Industrial Complex. Russia

⁵ Plekhanov Russian University of Economics, Department of Finance and Prices. Russia

* *Corresponding author*
e-mail: serik.mira@rambler.ru

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RESUMO

O objetivo deste estudo foi avaliar a aplicação dos dessecantes e da secagem pós-colheita de sementes de soja em locais experimentais e de controle. Um total de 120 locais de estudo, em quadruplicada, foram divididos em dois grupos de 60, um dos grupos não foi pulverizado com dessecantes (local de controle), o outro recebeu tratamento com dessecante (local experimental). Após uma semana de experimentos, as sementes dos locais experimentais apresentavam 1,5 vezes menos umidade do que as sementes dos locais controle ($p \leq 0,05$). A atividade da lipase tornou-se evidente ao máximo no período de até 50 dias. A atividade da lipoxigenase aumentou de 50 para 100 dias de armazenamento. A atividade da lipase nas sementes aumentou significativamente a 60 °C ($p \leq 0,05$), mas com o subsequente aumento da temperatura para 80 e 100 °C, uma redução notável foi registrada ($p \leq 0,01$). Para a lipoxigenase, uma diminuição semelhante na reação de atividade foi observada em temperaturas de agentes secantes a partir de 80 °C. Para outros fatores, nenhum resultado semelhante foi registrado. Isso significa que a atividade de enzimas, em particular a lipase e a lipoxigenase, desempenha um papel fundamental nos processos fisiológicos das sementes de soja durante o armazenamento, mas pode ser inibida em temperaturas a partir de 80 °C. A aplicação de dessecantes acelera a maturação da semente até o teor de umidade necessário por duas semanas. Após sete dias de tratamento com Reglon, o amarelecimento dos grãos e folhas na parte inferior das plantas de soja foi observado, pois o teor de umidade das folhas e grãos diminuiu para 35%, enquanto no local de controle, esses valores foram de 48% ($p \leq 0,05$).

Palavras-chave: *Soja, umidade das sementes, secagem, lipase, lipoxigenase, armazenamento.*

ABSTRACT

The purpose of the study was to evaluate the efficacy of soybean seed treatment with desiccants and through post-harvest drying. A total of 120 quadruplicate study sites were divided into two groups of 60, one of which was not sprayed with desiccants (control sites), and the other received desiccant treatment (experimental sites). A week after the beginning of the experiment, seeds from experimental sites had 1.5 times less moisture content than seeds from control sites ($p \leq 0.05$). The peak lipase activity of seeds was recorded during the first 50 days of storage. The lipoxigenase activity was found to increase between 50 and 100 days of seed storage. The activity of lipase in seeds increased significantly at 60 °C ($p \leq 0.05$), but with the subsequent increase in temperature to 80 and 100 °C, a noticeable reduction was recorded ($p \leq 0.01$). For lipoxigenase, a similar

decrease in activity reaction was noticed at temperatures of drying agents starting from 80 °C. For other factors, no similar results were recorded. This means that the activity of enzymes, in particular, lipase and lipoxygenase, plays a key role in the physiological processes of soybean seeds during storage, but can be inhibited at temperatures starting from 80 °C. Desiccants application accelerates the maturation of the seed to the necessary moisture content for two weeks. After seven days of treatment with Reglon, the yellowing of beans and leaves in the lower part of soybean plants was noted as the moisture content of leaves and beans decreased almost twice to 35%, while on the control site, these values were 48% ($p \leq 0.05$).

Keywords: Soybean, seeds moisture content, drying, lipase, lipoxygenase, storage.

АННОТАЦИЯ

Цель данной работы – оценить возможности комбинированного применения десикантов и послеуборочной сушки семян сои в сравнении с контролем. В 4-х кратной повторности заложено 120 участков, 60 – контроль (без применения десикантов) и 60 – эксперимент (два десиканта – Реглон супер и РАП). Спустя 1 неделю разница во влажности между контролем и экспериментом составила 1.5 раза. При сушке семян активность липазы в максимальной степени проявляется на сроках хранения до 50 суток. Для липоксигеназы активность возрастает от 50 до 100 суток. При 60 С активность липазы в семенах возросла достоверно ($p \leq 0.05$), но с последующим повышением температуры до 80 и 100 С значительно спадала ($p \leq 0.01$). Для липоксигеназы подобная реакция спада активности зафиксирована при температурах сушильных агентов начиная с 80 С. Для других факторов подобных закономерностей не зафиксировано. Это значит, что активность ферментов, в частности липазы и липоксигеназы играет ключевую роль в физиологических процессах в семенах сои во время их хранения, но может ингибироваться при температурах от 80 С. Применение десикантов по сравнению с контролем на 2 недели ускоряет созревание семян до необходимого режима влажности, без снижения показателей урожайности. Через 7 дней при обработке Реглоном и РАП в 2.0 раза по сравнению с контролем до 35 % снизились показатели влажности семян, в контроле эти показатели были 48 % ($p \leq 0.05$).

Ключевые слова: Соя, влажность семян, сушка, липаза, липоксигеназа, хранение.

1. INTRODUCTION:

With the constant growth in the world's population, the food problem is becoming increasingly relevant. Since seeds of legumes and cereals comprise the basis of the people's food ration, not only the issues of increasing yields but also the development of effective methods for drying seeds to prevent their damage by insects or fungi remain relevant (Chen *et al.*, 2020). The task to ensure that crops and legumes production meets the world quality standards is of high importance (Kambhampati *et al.*, 2020).

Numerous factors can affect the quality of crops after harvesting. For example, post-harvest crops processing requires drying, which, afterward, might influence the quality of crops and beans (Chahtane and Lopez-Molina, 2017).

The drying of crops and legumes is a complex technological process (Gouly and Gusov, 2019). According to numerous data, the correct arrangement of the drying process results in obtaining products (crops) of high quality (Burkhead and Klink, 2018; Fraser *et al.*, 2016; Nayak and Panda, 2016). Normally, three main factors are considered, namely, the properties of the biomaterial itself (seeds of legumes and

crops), the construction of the dryer, and the mode in which the dryer operates. These factors are interrelated as they determine the result (Statsenko *et al.*, 2020).

There are two main methods known for drying crops and beans. The first is the steam drying of seeds, and the second is liquid drying (Ye *et al.*, 2008). The first involves the conversion of liquid to steam and is called heat drying. During this process, the energy that may be required by the crops or beans is transferred by applying convection, conduction, or thermo-radiation processes, as well as through the electric field of high-frequency currents. Individual crop parameters, such as the moisture bond strength of beans or crops, should be considered as well (Anand *et al.*, 2019).

The second type of drying is called sorption drying, as the mechanism is based on the contact between raw grain material or beans and a substance with sorption properties (Munder *et al.*, 2019). The sorption methods vary from dry crops to the use of granulated silica gel or other substances (Li *et al.*, 2002).

A separate place in the production of vegetable oils from other oilseeds belongs to soybean. This plant is from the family of legumes

(Fabaceae) and refers to oilseeds in world practice, although, in Russia, it is considered a grain legume agricultural crop (Petibskaya, 2012). In Russia, this crop is primarily intended for protein production despite the predominant oil production from soybeans. This is due to the lack of or high costs for the standard source of protein - meat - in Russia and practical application (Yatchuk, 2013). It is known that protein comprises 35 to 50% of soybean content, the rest are carbohydrates (23 - 25%) and fats (18 - 22%). In terms of protein content, soybean outperforms peas by 1.5-2.0 times (22 - 25% protein in peas), in fat content – by 9-10 times (2%), but is twice as lower in carbohydrate content compared to peas (55%) (Dospekhov, 2014).

The soybean is of very high importance in vegetable oil production, accounting for about 30% of the global total oil production volume. In comparison, sunflower has a share of only 15%, and slightly more (17 %) takes rapeseed (Bergimostyan and Tikhonova, 2016).

The main soybean areas are located in the United States, Brazil, and Argentina, and, together, they account for up to 80% global yield volume amounting to 20-25 cwt per hectare (Haire-Joshu and Tabak, 2016; He *et al.*, 2014). However, the maximum soybean yield is still harvested in Italy with a volume of 37 to 40 cwt per hectare (Huang *et al.*, 2018). In Russia, soybeans have recently started to gain popularity as a mass agricultural crop. Thus, in the Oryol region, the yield was 21 cwt per 1 ha. In 2011, the same amount was harvested the Chuvash Republic, and slightly less - 19 cwt per 1 ha. In the Belgorod region (Petibskaya, 2012). It should be noted that most soybeans are imported to Russia from abroad, and all products belong to genetically modified varieties. Given the controversial role of GMOs in the aspect of negative impact on human health, which is still actively discussed in the scientific community, it would be most reasonable to cultivate "clean" soybeans in Russia (Kaymak, 2014; Klose *et al.*, 2015; Liu *et al.*, 2016).

Among the disadvantages of soybeans as a crop in the Russian climate is the low yield due to the late maturation of seeds as the harvesting season begins in September - October (Bergimostyan and Tikhonova, 2016). Therefore, the issue of developing methods to regulate the processes of moisture release in grains in the period before harvesting (the use of so-called desiccants) remains quite urgent. The development of methods accelerating the maturation of soybean seeds will allow obtaining better quality and earlier terms of their harvest.

Equally important and relevant is the issue of drying seeds after harvesting. Both directions are considered in this study. The combined use of desiccants and post-harvest drying of soybean seeds is assumed to enable getting the yield of this agricultural crop in the climatic conditions of Russia in earlier terms. Besides, the research results can be applied as an example for regions with a similar climate.

The purpose of this work was to explore the possibilities of combined application of desiccants and post-harvest drying of soybeans with an emphasis on the yield of this crop. The objectives of the study were: a) to study the effect of desiccants on the yield and sown properties of soybean seeds, and b) to assess the efficacy of post-harvest drying of soybeans at different temperatures.

2. MATERIALS AND METHODS:

2.1. Research design

The research was conducted between 2017 and 2019 in the Moscow Region (Russian Federation). The fields of the Seed Science Laboratory of the Agrarian Institute of the Russian Academy of Sciences were used as pilot sites, the area of each site was 10 m². Each experiment was set in 4-times repetition with a randomized variant of placement. In total, 120 sites were set.

2.2. Equipment

Soybean seeds were sown by the seed drill SCS-6-10 (Russia) with a given width between the rows of 0.45 m. It has been considered that the normal indicator of soybean seed germination will be 600 thousand per 1 hectare. Fertilizers were applied following generally accepted norms under a scheme of nitrogen 30, phosphorus 45, and potassium 45. Harvesting was carried out simultaneously in all sites utilizing a Sampo harvester (model 130). All experimental sites had the same type of soil, which unified the data from the experiment. The same version of soybeans, the Lancet, was examined.

2.3. Field studies

The first experiment involved determining the effect of desiccants considering such factors as the application of two desiccants simultaneously (Super Reglon, RAP), the consumption rates of these desiccants, and

different terms of soybeans treatment with desiccants. The last factor included the following characteristics: a) at the seed moisture content of 60% to 65%, when the yellowing of leaves in the lower tier of the plant begins; b) at the seed moisture content of 45 to 59%, when the beans in the lower and middle tiers of soybean plants are colored in brown; c) at the seed moisture content of 30 to 44% when all the beans in each soybean plant become brown.

Plants were sprayed with the help of hand sprayer OP-1.5 under the same favorable weather conditions, namely, on dry and windless days. Among the factors influencing desiccation are the temperature of the air and soil (external), the growth course of the plants themselves (internal), and the rate of moisture loss in soybean seeds and stems (internal in response to external factors). Every day, the seeds and stems moisture content indicators were evaluated using the Wille 55 device (Ministry of Agriculture of the USSR, 2004).

The second experiment was a continuation of the first one and aimed to determine the germinating capacity of soybean seeds depending on treatment with desiccants (Dospekhov, 2014).

To assess the impact of technological processes, the harvested soybean seeds of the same variety with initial moisture indexes of 9-10 % were selected. For each study, 30 samples of seeds were taken with moisture indices were set up to 14% by humidification. Each sample was treated with toluene to prevent spoilage from bacteria and fungi in soybean seeds. Seeds were stored at the 80 % humidity regime. Each of the samples was placed on the bottom of a special dish, an exciter, which also contained a sodium chloride solution to ensure constant air humidity. Individual small containers of toluene were placed in the same excitors to prevent the development of microorganisms and fungi during storage. Seed drying was performed under 60, 80, and 100 °C temperature conditions of the drying agents. At that, seeds were actively ventilated with constant air humidity and amount that flowed through the seed layer in a unit of time. The treatment was considered completed when the moisture content indicators of the seed corresponded to those of the equilibrium moisture at the given air humidity parameters.

The impact of technological processes on seed quality was evaluated based on the activity of enzymes, namely, lipase A, lipoxygenase A, and concentrations of phospholipids, chlorophyll A, and iodine number of phospholipids. The concentration of raw oils in soybean seeds, the

peroxide, and acidic numbers of oils in seeds were also determined. To determine the activity of lipase A, lipoxygenase A, the concentration of phospholipids, chlorophyll A, the authors used the standard methods proposed by GOST (state standard) 7825-96 (Soybean oil. Specifications), and to determine the acid, iodine, and peroxide numbers, the recommendations of GOST 10858-77 were used (Oilseeds crops. Industrial raw materials. Methods of determination of acid value).

The concentrations of various substances (e.g., chlorophyll A), acid value, iodine value, and peroxide value were determined by carrying out experiments according to Ermakov (1987). The acidity or acid value was determined using a 25 cm³ sample of soybean seed filtrate titrated with 0.1 M KOH solution in the presence of phenolphthalein indicator. The difference in weight between the flask was filled with dried oil, and the empty flask was determined after heating the sample at 105 °C for 1 hour (Ermakov, 1987).

Chlorophyll A was determined through chromatography using an alcohol extract in the presence of 10 ml of gasoline. Lipids were extracted using a chloroform-methanol 1:2 (v/v) mixture. Common phospholipids were quantified by phosphorus determination after mineralization with perchloric acid (Ermakov, 1987).

The lipase and lipoxygenase activities were assayed using the different buffers: an alkaline phosphate buffer (pH 8.0) and an acidic acetate buffer (pH 4.7). The iodine value was determined with the Hubl method. For this, an ICl reagent and a reagent mixture of HgCl₂ and Cl₂ were applied. The peroxide value was determined by dissolving the soybean seed sample in a solution containing 70% acetic acid and 10% potassium iodide. The resulting iodine was titrated with sodium hyposulfite (Ermakov, 1987).

Thus, the indicators mentioned above during drying and active ventilation of seeds were determined after soybean seeds were maintained for 1 day after treatment. The storage modes of 0, 50, and 100 days were compared.

2.4. Statistical analysis

Statistical analysis of the data obtained was carried out using the Statistica program (StatSoft Inc., v. 6.0). The arithmetic mean for each parameter, like the concentration of enzymes and oils, amount of seeds, and the error of the mean, was estimated. The significance of differences was checked using the t-test for independent samples. Due to the normal

distribution of features within the sample, the methods of parametric statistics were applied.

2.5. Research limitations

Climatic conditions in different years of the research varied in terms of air and soil humidity and precipitation. Therefore, soybean maturation time could change by one week forward or backward from the average period in a given region. For this reason, Figure 1 depicts the data for the year 2018, which most corresponds to the norms in conditions of moderate continental climate in Russia.

3. RESULTS AND DISCUSSION:

3.1. RESULTS

The obtained results show that the use of desiccants allows for a significant reduction of the soybeans aging time with the possibility of earlier harvesting (Figure 1).

The first treatment with desiccants was carried out on August 11, 2018. This year was chosen for the description in Figure 1 as climatic indicators met the average norms for the research region. After seven days of treatment with Reglon, the yellowing of beans and leaves in the lower part of soybean plants was noted as the moisture content of leaves and beans decreased almost twice to 35%, while on the control site, these values were 48% ($p \leq 0.05$). The results similar to the Reglon application were observed in the accounting areas with RAP treatment as well. Another eight days later, on August 27th, leaf shattering occurred in the lower and middle parts of plants in the control sites. Moisture content here decreased to 35%. For sites treated by the Reglon and RAP, grain moisture content was recorded at 25%, which is one third less than that of the control site ($p \leq 0.05$). Finally, by September 8th, the moisture content difference between the control and the experiment remained significant - 1.5 times ($p \leq 0.05$). Crops acquired yellow color, beans became dark brown, and leaves completely crumbled. Thus, the use of desiccants is justified as it allows harvesting already two weeks earlier than in the control site, i.e., at the end of August.

No significant differences in yield between control and experimental sites were recorded. Thus, with an increase in the Reglon concentration, there is a tendency to yield reduction on the experimental sites compared to the control ones. The same tendency is noted when applying RAP preparation. Simultaneously,

the average yield values on experimental and control sites do not statistically differ from each other and can be compared with losses from insect pests or the activity of bacteria and fungi.

The data obtained on the application of desiccants are directly related to the second part of this research as the less moisture the soybean seeds contain, the less time it takes to dry them.

It has been established that with the seed storage periods of up to 50 days, a minor activity of enzymes without significant differences is observed (Table 1).

At that, lipase activity maximally manifests itself during the retention period of up to 50 days (at $p \leq 0.01$). It decreases slightly at storing for up to 100 days ($p \leq 0.05$), while lipoxygenase activity increases, on the contrary, between 50 and 100 days of storage (at $p \leq 0.01$). Throughout the experiment, no significant differences have been established in acid and peroxide numbers, in the oil concentration of the seeds, and, also, for active seed ventilation. On the other hand, significant differences occur during drying seeds at different temperatures of drying agents. Thus, lipase activity in seeds increased significantly at 60 °C ($p \leq 0.05$), but with the subsequent increase in temperature to 80 and 100 °C, a noticeable reduction was recorded ($p \leq 0.01$). For lipoxygenase, a similar decrease in activity reaction was noticed at temperatures of drying agents starting from 80 °C. For other factors, no similar results were recorded. It means that the activity of enzymes, particularly lipase and lipoxygenase, plays a key role in the physiological processes of soybean seeds during storage, but can be inhibited at temperatures starting from 80 °C.

3.2. DISCUSSION:

The established pattern of increasing physiological activity of enzymes in soybean seeds with higher moisture content is also known from other studies (Liu *et al.*, 2016, 2017a, 2017b; Bachleda *et al.*, 2017; Abatiet *et al.*, 2017). However, the physiological activity of enzymes directly determines the quality of the soybean seeds, as shown in this study and other authors (Bishawet *et al.*, 2012). The activity of lipase enzyme during storage for up to 50 days suggests different maturation degree of soybean seeds in the post-harvest period. The activity of lipase and lipoxygenase can be used as a marker and other features of soybean seed quality, particularly its moisture content, as suggested by other authors (Corbineau, 2012).

Storage conditions are also important for maintaining soybean seed quality as they determine the intensity of the physiological processes occurring in soybean seeds (Di Girolamo and Barbanti, 2012). On the other hand, the use of desiccants is justified, as shown by the data obtained through this research and other studies (Carvalho *et al.*, 2017), because it reliably shifts the harvesting time by one and a half to two weeks in a temperate continental climate. Pre-harvest seed quality plays a decisive role in seed preservation in the post-harvest period. During harvesting, the moisture content determines the necessity and duration of their further drying (Pereira *et al.*, 2015). Some studies point to the restriction factor, not climatic as considered in this study, but physiological as the content of lignin in soybean seeds determines their defective qualities (Yamashita *et al.*, 2017). In this research, standard soil conditions for Russia have been considered, namely, chernozem. Although, on saline soils, stress factor can also restrict normal development of soybeans (Shu *et al.*, 2017).

At a longer storage period from 50 days to 100 days, a significant change in the variety of seed mass occurred with increasing activity of enzymes.

Among applied technological processes, active ventilation did not initiate significant changes in the studied parameters, particularly maintaining the activity of enzymes at the same level or reducing it. Similar results were obtained by other authors (Shi *et al.*, 2016). Nevertheless, the effect of temperatures from 80 to 100 °C during drying significantly reduces the activity of enzymes, which allows prolonging the storage time of seeds. Other results obtained through this research are closely related to this process. Thus, the use of desiccants enables obtaining seeds with the given low parameters of moisture content, which will subsequently reduce the cost of drying the seeds and perform harvesting in earlier terms.

The heterogeneity of the seed mass increases with the rise in temperatures of the drying agent, which can be explained by the unevenness of the heating process in the dryer. Besides, seeds are dehydrated uneven as well. As the temperature increases up to 100 °C, the inhibition of enzymes occurs, which is also due to the uneven heating.

4. CONCLUSIONS:

The storage periods of soybean seeds for more than 50 days and modes of drying with temperatures of 100 °C, results in the deterioration of the seed mass quality. It has been established

that the lipase and lipoxygenase enzymes remain inactive at the maximum temperature values that worsen, thus, the quality features of seeds like raw oil mass, acid, and peroxide numbers. However, the activity of enzymes decreases during drying, and with active ventilation of the seed mass, such a pattern is not detected. It has been established that the use of desiccant accelerates the maturation of seeds to the required regime of humidity for two weeks compared to the control site, without a significant decrease in yield amounts.

At that, the lipase is active to the maximum extent at the storage of up to 50 days (at $p \leq 0.01$) and less active at storing for up to 100 days ($p \leq 0.05$), while the activity of lipoxygenase increases between 50 and 100 days of storage (at $p \leq 0.01$). Throughout the experiment, no significant differences have been established in acid and peroxide numbers in the oil concentration of the seeds. Significant differences occur during drying seeds at different temperatures of drying agents. The activity of lipase in seeds increased significantly at 60 °C ($p \leq 0.05$), but with the subsequent increase in temperature to 80 and 100 °C, a noticeable reduction was recorded ($p \leq 0.01$). For lipoxygenase, a similar decrease in activity reaction was observed at temperatures of drying agents starting from 80 °C. Other results obtained through this study are inextricably related to this process. Applying desiccants allows producing seeds with given low parameters of moisture content, which subsequently contributes to cost reduction at seeds drying and harvesting in earlier terms.

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Figure 1. Changes in soybean seed moisture indices depend on treatment with two desiccant preparations (Region, RAP-600) compared to the control site (without treatment) according to data from 2018. The Region was applied in the amount of 1.5 liters per 1 ha., and RAP – 2.5 liters per 1 ha.

Table 1. Enzyme activity and oil concentration indices in soybean seeds depending on the type of technological exposure

Form of exposure	Activity of lipase *	Activity of lipoxigenase **	Acid number***	Peroxide number ****	Concentration of raw oils in seeds, %
Retention terms					
0 days, moisture content 14 %	12 ± 4 ²	24 ± 3 ¹	1.8 ± 0.3	10.0 ± 0.4	17.9 ± 0.2
50 days	22 ± 2 ²	33 ± 5 ²	1.8 ± 0.3	10.1 ± 0.3	18.0 ± 0.3
100 days	31 ± 4 ¹	66 ± 9 ²	2.0 ± 0.2	11.7 ± 0.8	18.1 ± 0.1
Active ventilation					
Ventilation of starting seeds at moisture content of 14 %	21 ± 3	26 ± 3	1.8 ± 0.4	10.1 ± 0.2	18.3 ± 0.2
Ventilation of seeds dried until moisture content of 12.5 %	29 ± 3	34 ± 7	1.8 ± 0.3	11.1 ± 0.5	18.4 ± 0.1
Drying					
Starting seeds, moisture content 14 %	22 ± 3 ¹	26 ± 4	1.8 ± 0.2	10.2 ± 0.3	18.3 ± 0.2
Dried seeds 12.5 %	35 ± 4 ¹	26 ± 4	2.1 ± 0.6	10.6 ± 0.3	18.4 ± 0.1
Temperature of the drying agent 60°C					
80 °C	28 ± 3 ²	30 ± 5 ²	2.4 ± 0.5	11.1 ± 0.4	18.3 ± 0.2
100 °C	14 ± 4 ²	12 ± 6 ²	2.6 ± 0.6	13.8 ± 0.5	18.5 ± 0.3

Note: Units of measure: * - mmol C18 / mg*min 10-3, ** - mmol O2 / mg*min *10-4, *** - mg KOH, **** - 1 / 2 mmol O / kg. Significant differences: 1 - at p ≤ 0.05, 2 - at p ≤ 0.01.