**FEB - FRESENIUS ENVIRONMENTAL BULLETIN**
Founded jointly by F. Korte and F. Coulston
Production by PSP - Vimy Str. 1e, 85354 Freising, Germany in
cooperation with PRT-Parlar Research & Technology - Vimy Str 1e, 85354 Freising


**Printed in Germany-ISSN 1018-4619**

**Fresenius Environmental Bulletin is abstracted/indexed in:**
**Biology & Environmental Sciences, BIOSIS, CAB International, Cambridge Scientific abstracts, Chemical Abstracts, Current Awareness, Current Contents/Agriculture, CSA Civil Engineering Abstracts, CSA Mechanical & Transportation Engineering, IBIDS database, Information Ventures, NISC, Research Alert, Science Citation Index (SCI), Scisearch, Selected Water Resources Abstracts**

# CONTENTS

## ORIGINAL PAPER

# THE POSSIBILITY OF SUSTAINABLE PRODUCTION OF BUCKWHEAT AND QUINOA CROPS ON MODERATELY DEGRADED LAND IN VOJVODINA (NORTHERN SERBIA)

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## ABSTRACT

This study analyzes the possibility of sustainable production of high biological value food, quinoa and buckwheat, on a fertile agricultural and moderately degraded land – in an area outside their native range. The research was conducted during three consecutive years on two locations and two types of soil in Vojvodina, the Republic of Serbia, and included one variety of quinoa (KVL 52.2) and one variety of buckwheat (Novosadska). The trial was set up in the city of Nova Pazova (on fertile meadow black soil) and the village of Ilandža (on degraded marshy black soil). The aim of the research was to determine the impact of pedological conditions on the sustainable production of quinoa and buckwheat in different locations in Vojvodina. It was found that moderately degraded land can be used for sustainable production of high-value food without the prior application of agro-ameliorative measures. The yield of buckwheat was significantly higher and less influenced by pedological conditions than the yield of quinoa, suggesting the use of this alternative crop species for the production of high-quality food on moderately degraded land in Vojvodina.

**KEYWORDS:**
Buckwheat, Quinoa, Sustainable Production, Degraded land, Serbia

## INTRODUCTION

Sustainable Development Goal 2 (Zero Hunger) seeks to "end hunger, achieve food security and improved nutrition and promote sustainable agriculture" [1]. Sustainable agriculture is considered to be the eco-efficient production of high-value quality food with minimal use of land and investment [2]. The basis for the production of high-value food is the preservation of land, which contributes to local and global security in the supply of food to population [3]. It has been estimated that as much as 93% of the food products received by modern society is owed to the fertility of agricultural land. Hence, it is an alarming fact that the areas of arable land are decreasing, while the world's population is growing [4]. It is estimated that an increase of as much as 60% in global food production and related ecosystem services will be needed by 2050 [3]. On the other hand, the area of degraded land has significantly increased in recent decades, which greatly reduces its production potential, and thus the amount of produced usable goods [5]. One third of the world's arable land today is undergoing moderate or intense soil degradation processes [3]. Factors contributing to soil degradation are erosion, reduction of organic matter, increased amount of harmful and dangerous substances, salinization, alkalization, acidification, flooding, repurposing, and loss of biodiversity [5].

Diversification of crops contributes significantly to the security of food supply and nutrition improvement, which can have a positive effect on soil fertility and pest control in agricultural production. Hence, one of the ways to contribute to sustainable agriculture can be the use of alternative grains in the diet, i.e., the introduction of new or neglected plant species in agricultural production, such as quinoa (*Chenopodium quinoa* Willd., fam. Chenopodiaceae) and buckwheat (*Fagopyrum esculentum* Moench, fam. Polygonaceae) [6]. Alternative grains have several advantages over true cereal grains (fam. Poaceae). First of all, they have high nutritional value of the main product (grains), while their by-products (leaves, stems, etc.) are used in various industries. Another advantage is that they show great tolerance to growing conditions (climate and soil); thus, they can be successfully grown in different areas and under different environmental conditions. In addition, compared to many other field crops, alternative grains are more tolerant of environmental pollution [7] and most of these grains can be grown very successfully on degraded lands [8]. The technological advantage is their short vegetation, which allows them to be grown as a stubble crop, which increases the total annual profit from the agricultural area [7]. During the vegetation period, they are attacked by a small number of pests, so they can be easily grown in a system of organic and sustainable agricultural production. Since being gluten-free, they are classified as food products that can be used by people with celiac disease [9]. Buckwheat and quinoa are nutritionally valuable food that can meet the daily needs of most essential amino acids, and as such can have numerous benefits for human health if consumed as part of various food products [10]. Still, in addition to crop diversification, provision of protection, application of the latest technologies and pest control, it is necessary to stimulate scientific research in this field. One of the operational goals of the "Strategy of Agriculture and Rural Development of the Republic of Serbia for the period 2014-2024" [11] implies more efficient use of low-quality land. The aforementioned, as well as the fact that quinoa and buckwheat are considered to be the food of the future in the fight against hunger [12], have determined the subject of the research presented in this paper.

Arable land occupies over 65% of the territory of Serbia, and the soils that are most suitable for crop production are located in the country's flatlands – Vojvodina [13]. According to all their production properties, these soils are mostly among the best soils in Europe and in the world [14]. The most widespread types of soil in Vojvodina include chernozem, meadow black soil and marshy black soil – on which almost all cultivated plants are grown (44%, 17% and 16%, respectively). These soils have a high fertility potential and represent the basis of agricultural production capacity in Serbia. The endangerment of the mentioned pedosystematic units in Vojvodina is most often related to contact with salt marshes, and it is expressed as a high or low degree of loading with harmful mobile salts [5]. In order for degraded soils to become suitable for the production of conventional field crops, it is necessary to perform a series of interventions to improve their physical, chemical and biological properties, which is a time-consuming, demanding and expensive process. On the other hand, buckwheat and quinoa are plants originating from areas with less favorable climatic and soil conditions than those usually prevailing in Serbia, so that crops of these plants on local agricultural lands give higher yields and nutritional value of grain than in the countries of their origin. In addition, in Serbia, areas under alternative grains are still insufficient to meet the growing needs for their production [13]. Therefore, the assumption is that the use of alternative field crops, such as buckwheat and quinoa, which are resistant to various agro-ecological conditions, represent the potential for the production of high biological value food on low-quality lands.

Numerous authors have recently studied the physical, chemical and nutritional properties of alternative grains, including buckwheat [e.g., 15–18]. For instance, some authors [15] looked into the chemical composition of buckwheat grains from a nutritional aspect. They stated that buckwheat is a type of alternative grain with high nutritional value, whose phytochemical composition from the nutritional perspective is significantly higher compared to small grains and millet grains, which is expressed in terms of quantity and quality of proteins, vitamins, minerals, phytosterols, and antioxidants. A number of field trials of buckwheat was conducted in Serbia, as well. Summarizing the results of numerous studies, some authors [13] noted significant variations in the values of yield parameters, but still overall satisfying grain yield. Meanwhile, other authors [e.g., 19–22] have recently studied the nutritional characteristics of quinoa and the possibility of its sustainable production. For example, one research [22] focused on characterizing the amino acid profiles of quinoa, buckwheat and amaranth proteins, pointing out that buckwheat, quinoa and amaranth are nutritionally valuable raw materials that can meet people's daily needs of most essential amino acids. According to one study [13], quinoa has been grown in experimental fields in Serbia for about ten years, with results showing that this species can be grown in all parts of the country with small variations in grain yield and that agroecological conditions have had little impact on grain quality. Still, although quinoa and buckwheat production has already been the subject of many studies in the world and in Serbia, due to different research approaches, sufficient data on the possibility of sustainable production of high-value food on degraded land is not available, which prompted the need for further research of these species.

This paper analyzes the results of research conducted in the northern part of Serbia (Vojvodina), addressing the subject of the possibility of sustainable production of high biological value food on low-quality land. They were obtained by analyzing the variability of selected morphological and production characteristics of buckwheat and quinoa at different sites, by comparing the productivity of these two field crops in different pedological conditions. The aim of the research was to evaluate the possibility of establishing sustainable production of buckwheat and quinoa on fertile and moderately degraded land in order to answer the question of whether degraded soils can be used for sustainable production of high biological value food, without prior agromelioration.

## MATERIALS AND METHODS

The data on the variability of morphological and productive traits of buckwheat and quinoa were obtained by setting up a field trial in order to compare the productivity of these two species in different pedological conditions. Having in mind the concept of sustainable production, the productivity of growing these two alternative grains in northern

Serbia was compared in order to determine the sustainability of their production on fertile and moderately degraded land.

**Field experiment.** The field trial was conducted during three consecutive years (2017–2019) in two locations and on two soil types in Vojvodina and included one variety of quinoa ("KVL 52.2", University for Life Science, Copenhagen, Denmark) and one variety of buckwheat ("Novosadska", Institute of Agriculture, Novi Sad, Serbia). The trial was set up in Nova Pazova (on fertile land, meadow black soil) and Ilandža (on degraded land, marshy black soil). The marshy black soil in Ilandža has been exposed to excessive fertilization and irrigation in the last few decades, which led to salinization of the arable layer and redistribution of small aggregates and particles and worsened the water properties of this soil. At both locations, the thermal regime and the amount of precipitation in the vegetation period were monitored during the trial. The thermal regime was uniform per year and per location, while the amount of precipitation in the vegetation period, per year, ranged from 294 mm to 371 mm in Nova Pazova, and 211 mm to 309 mm in Ilandža. The crops were sown on four plots of 16 $m^2$ (4 x 4 m) in size. The sowing was performed every year at the beginning of April, with a manual single-row seeder, on a row spacing of 50 cm. Crop care consisted of manual weeding. Quinoa was harvested by hand in the second half of August, by cutting off stalk parts with inflorescences, which were subsequently dried in ventilated rooms. After drying, the grains were manually separated from chaffs and other plant residues by sieving. Manual harvesting of buckwheat was done in the second half of August.

**Morphological and yield measurements.** From all plots, 10 plants were selected from two middle rows for the analysis of morphological and productive characteristics. The grains were separated, and subsequently cleaned and dried to a moisture content of 10%. The yield was calculated at a given humidity and was determined by measuring the mass of separated seeds. The following morphological and productive characteristics of both species were analyzed: plant height (cm), grain yield (kg/ha) and biomass yield (kg/ha).

**Statistical analysis.** The obtained numerical data were processed by descriptive, univariate and multivariate statistical methods. Descriptive statistics included the determination of the following statistical parameters: mean value ($\bar{X}$), standard deviation (±SD) and coefficient of variation (CV, %). Using analysis of variance (ANOVA), principal component analysis (PCA), and cluster analysis (CA), the differences between the morphological and productive parameters of the two crops in different soil conditions were tested. All statistical analyzes were performed using Statgraphics software (ver. XVI.I., 2009; Statpoint Technologies, Inc., Warrenton, VA).

## RESULTS AND DISCUSSION

Due to the biological differences existing between the studied crop species, comparing the morphological and productive characteristics of quinoa and buckwheat is not meaningful, but these characteristics were simultaneously analyzed for both species, using statistical tests, in order to identify the differences in traits of the species when grown in different pedological conditions and to establish by comparative analysis which of these two crops is more productive on low-quality land. Based on trial data on the three studied morphological and productive traits, determined for one variety of buckwheat and one variety of quinoa, whose crops were produced during three consecutive years in different locations in Vojvodina, an overview is given of the results of successful cultivation of the two species of alternative grains on fertile and moderately degraded land (Table 1; Figure 1).

**Descriptive statistics.** The lowest recorded value of height for specimens of buckwheat grown on fertile land was 120.70 cm, while on moderately degraded land it was 100.70 cm. The highest value of the height of a buckwheat specimen grown on fertile land was 143.00 cm; on degraded land, it was less than the lowest value recorded on fertile land and amounted to 129.20 cm. The average height of buckwheat plants grown on fertile land is 135.89 cm, while on degraded land is 115.48 cm. On the other hand, the values of the height of quinoa specimens grown on fertile and degraded lands are similar. The lowest measured height of quinoa on fertile land was 112.00 cm, and, on degraded land, it was slightly higher (129.00 cm). In addition, the highest measured values of quinoa height on fertile and degraded lands differed only slightly from each other (152.00 cm and 150.00 cm, respectively), which also applies to the mean values of this morphological trait determined on specimens grown on fertile and degraded lands (144.30 cm and 141.07 cm, respectively). When it comes to the obtained biomass, the relationship between these two crop species was opposite to the example of the height of the specimens. The minimum amount of buckwheat biomass on fertile land was 5,420.00 kg/ha, and on degraded land was 4,185.00 kg/ha. The highest amount of biomass of this species on fertile land was 5,885.00 kg/ha and on degraded 5,570.00 kg/ha. The average values of this productive characteristic of buckwheat grown on fertile and degraded lands are 5,704.20 kg/ha and 4,801.70 kg/ha, respectively. On the other hand, the lowest amount of quinoa biomass obtained on fertile land was 945.00 kg/ha and on degraded land 540.00 kg/ha. The highest amount of biomass of this species on fertile land was 1,120.00 kg/ha and on degraded land 974.00 kg/ha. The average values of this productive characteristic of quinoa on fertile and degraded lands are 1,010.00 kg/ha and 804.40 kg/ha, respectively. As in the case of biomass, the yields of buckwheat on fertile and moderately degraded lands were more similar one to another than those obtained from quinoa. The lowest production of buckwheat on fertile land was 830.00 kg/ha, and on degraded land 626.00 kg/ha. The highest yield of buckwheat on fertile land was 980.00 kg/ha, while on degraded land 880.00 kg/ha. The average values of this productive characteristic of buckwheat on fertile and degraded lands are 912.97 kg/ha and 769.50 kg/ha, respectively. On the other hand, the lowest quinoa yield obtained on fertile land was 875.00 kg/ha, while on degraded land 488.00 kg/ha. The highest yield of quinoa on fertile land was 1,010.00 kg/ha, and on degraded land 710.00 kg/ha. The average values of quinoa yield on fertile and degraded lands are 946.63 kg/ha and 600.27 kg/ha, respectively (Table 1).

The obtained values of morphological and productive characteristics of the two field crops were compared with the corresponding literature data. According to these comparisons, the average biomass yield determined on buckwheat crops, on fertile and moderately degraded lands, was lower than the average value stated in the literature for a given characteristic of this species (8,312.70 kg/ha) [23]. The average yield of buckwheat on fertile land was almost close to the average yield of buckwheat in the world (913.00 kg/ha) [24], but lower than the yield of buckwheat stated by various authors for Serbia (1,180.00–2,263.00 kg/ha) [24, 25] and other areas (999.20–1,086.40 kg/ha) [16]. The average yield of this species on degraded land was about 16% lower than on fertile land and roughly corresponded to that recorded by one research [10] in western Serbia (800 kg/ha). Since data on the average height of buckwheat are not available in literature, their comparison with the measured values was not possible. On the other hand, the average height of quinoa on fertile land was close to that stated in the literature (144.00 cm) but was slightly lower than that stated for the studied quinoa variety (146.00 cm) [26]. The average height of quinoa specimens on degraded land (141.07 cm) was somewhat lower than that on fertile land. The average quinoa biomass obtained on fertile land was higher than the values stated in the literature for the studied trait of this species, while the amount of biomass obtained on degraded land corresponds to the range of values in the literature (717.90-982.90 kg/ha) [27]. The average quinoa grain yield on fertile land corresponds to the range of values reported in the literature for Serbia (690.00–1,509 kg/ha) [10, 26]. The average yield of quinoa grain on degraded land was almost 37% lower than that on fertile land, but this yield was still higher than that recorded by one study in 2012 (382.00 kg/ha) [6], which was a very dry year in Serbia.

According to the values of the coefficient of variation (CV), the studied morphological and productive characteristics of both studied species of alternative grains showed a low degree of variability (<10%) on fertile land. The same applies to all morphological and productive characteristics of buckwheat, as well as to the height of quinoa specimens on degraded land, while the quinoa biomass and yield obtained on degraded land showed a higher degree of variability (CV = 10–20%) (Table 1). This result confirms the data in the literature, according to which the coefficient of variation for the height of quinoa specimens ranged from 3.00% to 7.65%, while the grain yield had somewhat higher values (10.70–14.55%) [26] or significantly higher values of this coefficient (23.80–36.60%) [6].

**TABLE 1**
**Descriptive statistics, ANOVA (F-ratio and *P*-value), and factor loadings in principal component analysis (PC1 and PC2) for height, biomass and yield of buckwheat and quinoa raised on fertile (f. l.) and degraded lands (d. l.) in Vojvodina (northern Serbia).**

| | | Buckwheat | | | | | | Quinoa | | | | | | PCA | | ANOVA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | X̄ | | MIN | MAX | SD | CV | X̄ | | MIN | MAX | SD | CV | PC1 | PC2 | F | *P* |
| Eigenv. | | | | | | | | | | | | | | 1.56 | 1.18 | | |
| Percent | | | | | | | | | | | | | | 52.00 | 39.20 | | |
| Height | F. l. | 135.89 | b | 120.70 | 143.00 | 5.18 | 3.81 | 144.30 | a | 112.00 | 152.00 | 7.76 | 5.96 | **-0.81** | 0.49 | 115.17 | **0.0000** |
| | D. l. | 115.48 | c | 100.70 | 129.20 | 7.22 | 6.25 | 141.07 | a | 129.00 | 150.00 | 5.37 | 4.22 | | | | |
| Biomass | F. l. | 5704.20 | a | 5420.00 | 5885.00 | 134.21 | 2.35 | 1010.00 | c | 945.00 | 1120.00 | 55.47 | 5.49 | **0.92** | 0.20 | 4613.48 | **0.0000** |
| | D.l. | 4801.70 | b | 4185.00 | 5570.00 | 357.56 | 7.45 | 804.40 | d | 540.00 | 974.00 | 136.07 | 16.92 | | | | |
| Yield | F. l. | 912.97 | b | 830.00 | 980.00 | 46.14 | 5.05 | 946.63 | a | 875.00 | 1010.00 | 39.00 | 4.12 | 0.22 | **0.95** | 231.93 | **0.0000** |
| | D. l. | 769.50 | c | 626.00 | 880.00 | 66.72 | 8.67 | 600.27 | d | 488.00 | 710.00 | 69.36 | 11.56 | | | | |

**Note:** Mean values with different letters within a morphological or productive trait are significantly different at the 95% confidence level. Bold values indicate variables with factor loadings >0.70 in the principal component analysis (PCA) and *P* < 0.05 in the analysis of variance (ANOVA).

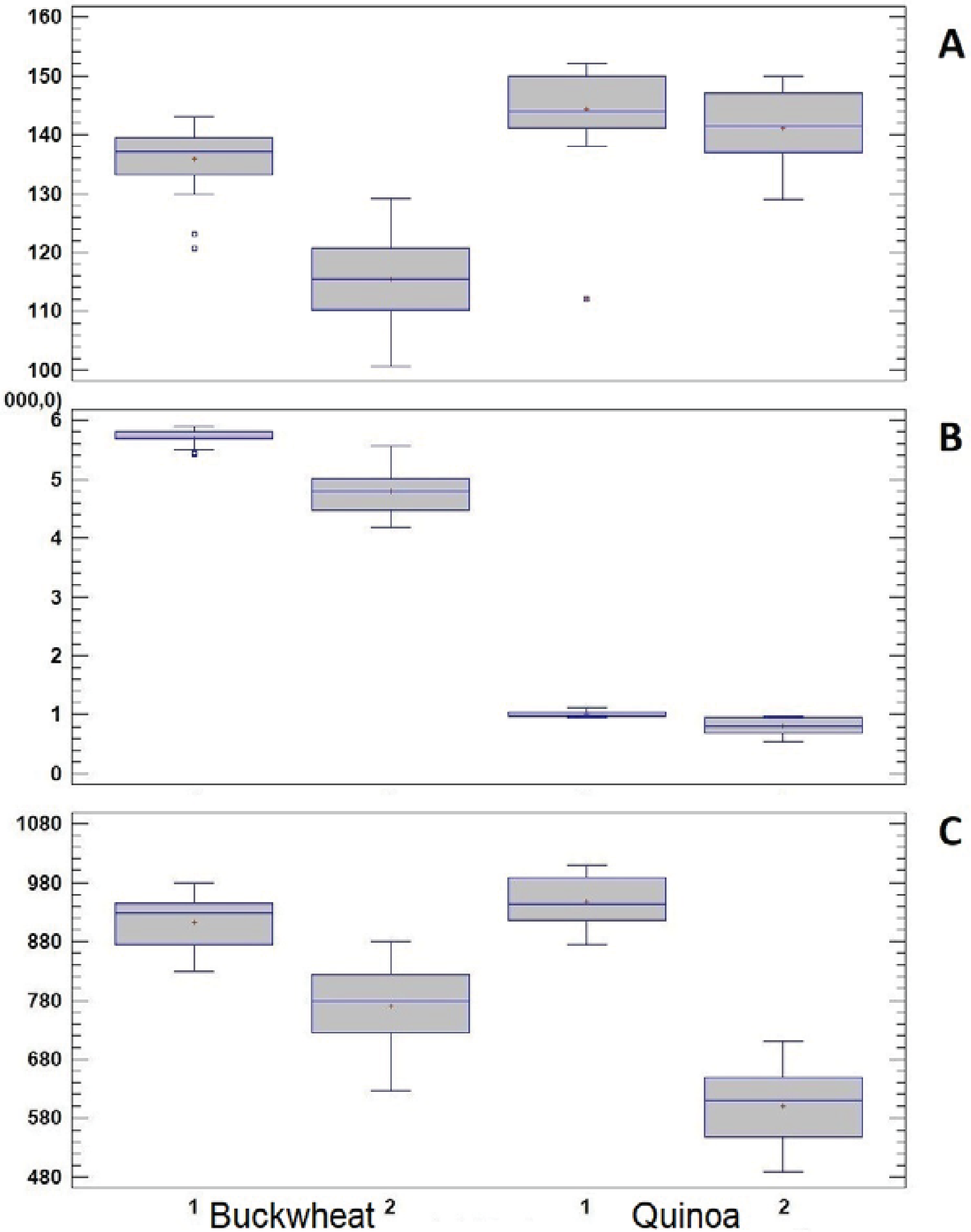


**FIGURE 1**
**Box-and-Whisker plots of basic statistical parameters for (A) plant height, (B) biomass, and (C) yield of buckwheat and quinoa raised on (1) fertile land, and (2) degraded land. Legend: middle sign – mean value, middle line – median, box – mean value and standard deviation, whiskers – range.**

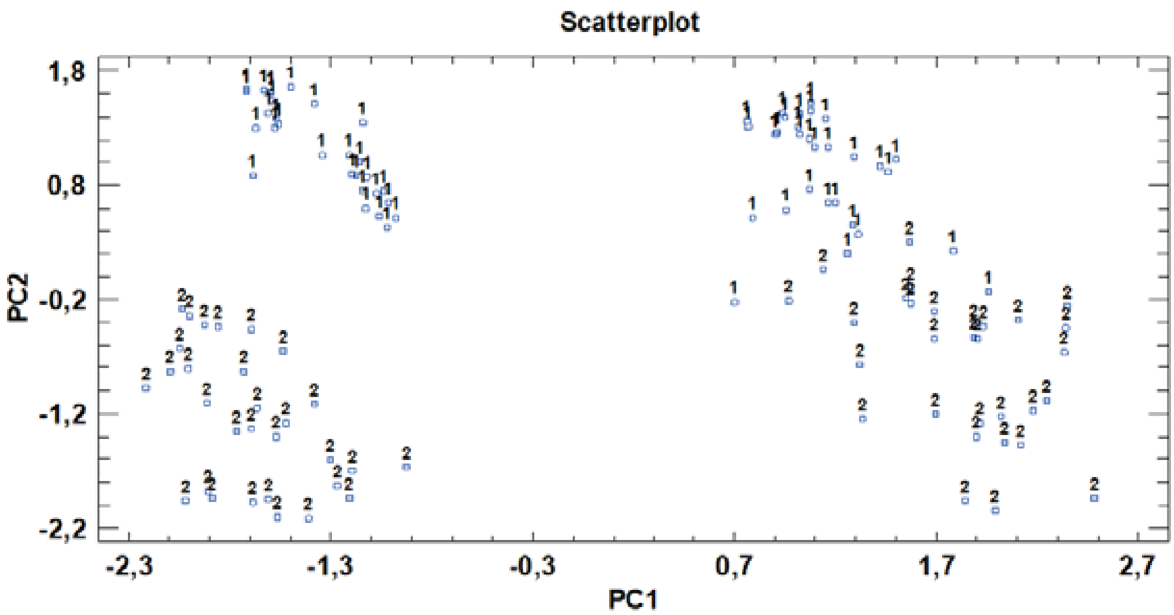


**FIGURE 2**
**Scatterplot in principal component analysis (PCA) for two species of alternative grains (the left group – quinoa, the right group – buckwheat) based on their height, produced biomass, and yield on (1) fertile land, and (2) degraded land.**

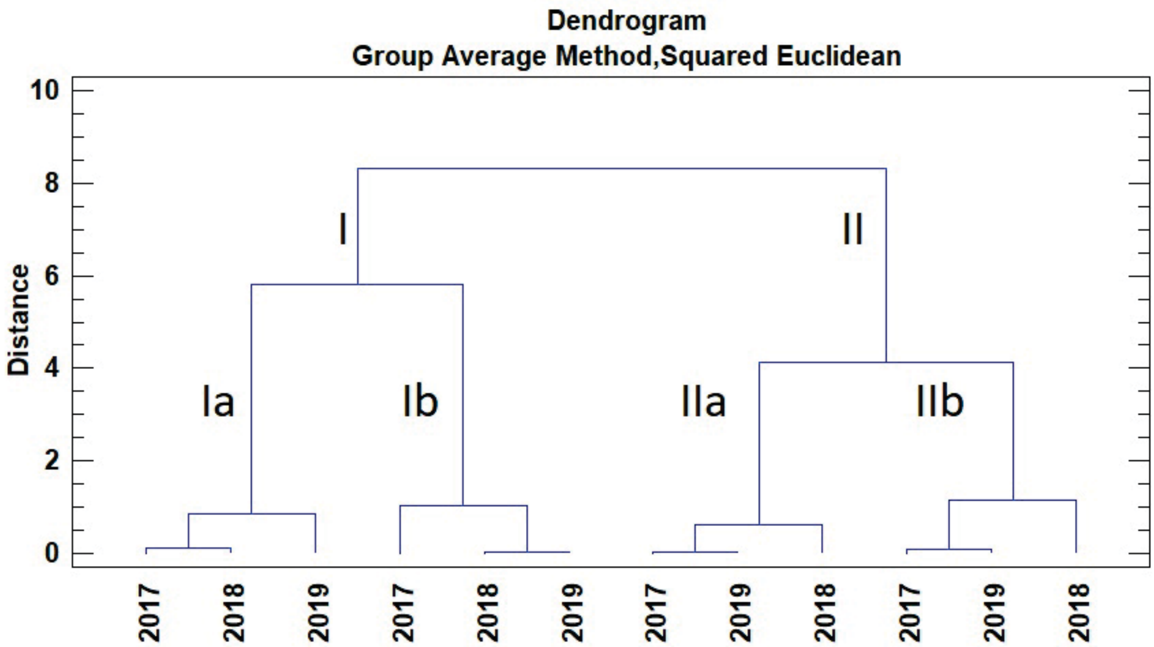


**FIGURE 3**
**Dendrogram showing the relationships between two species of alternative grains (I – quinoa, II – buckwheat) based on their height, produced biomass and yield during three consecutive years (2017–2019) on (a) fertile land, and (b) degraded land.**

**Analysis of variance.** The ANOVA showed significant statistical differences ($P$ = 0.00) between the mean values of all morphological and productive traits of the studied species. The highest contribution to species differentiation had the amount of biomass (F = 4,613.48), and the smallest – plant height (F = 115.17) (Table 1).

**Principal component analysis.** In the PCA, the first two principal components (with eigenvalues >1) were sufficient to explain as much as

91.20% of the total variation obtained for both studied species. Most of this variation was explained by the first axis (PC1 = 52.00%), and 39.20% by the second one (PC2). Two morphological and productive traits (plant height and biomass), with factor loadings >0.70, had an impact on the first axis, while the second axis was influenced by the yield (Table 1). As significantly less pronounced than the variation of shape (the second axis), the variation of size (the first axis) resulted in the separation of species along the first axis. Corresponding to the two studied crop species, two groups of points are formed, as shown in Figure 2. Points belonging to quinoa formed a group in the negative part of the first axis, in contrast to the points representing buckwheat that were grouped in the positive part of the same axis. Within these two groups, a clear-cut differentiation of points representing quinoa along the second axis can be observed depending on the land on which the corresponding specimens were raised (1 – fertile land, and 2 – moderately degraded land). The points that refer to the specimens grown on fertile land were grouped in the positive part of the second axis, and the points that refer to the specimens grown on moderately degraded land formed a group in the negative part of the same axis. On the other hand, in the case of the points related to the specimens of buckwheat, an overlap may be observed between the two groups, and there is only a trend of separation of the points related to the specimens that were grown on fertile land and those grown on moderately degraded land.

**Cluster analysis.** Similar to the results in the PCA, in the cluster analysis (CA) the studied crop species are differentiated into two main clusters, as shown in Figure 3. Within both of these clusters, two groups (subclusters) can be distinguished depending on the land on which the crops of these two species were produced, suggesting significant morphological and productive differences between the two species in relation to pedological conditions. The first group represents the quinoa specimens grown on fertile land (Ia) for three years, while the second group represents the specimens of this species grown on moderately degraded land (Ib). The third group represents the buckwheat specimens grown on fertile land (IIa), while the fourth group represents the specimens of this species grown on moderately degraded land (IIb). At the same time, it can be noticed that the first two groups are formed at a slightly greater linkage distance within the overall cluster than it is the case with the other two groups. This means that crops of buckwheat were morphologically and productively more homogeneous on fertile and moderately degraded lands compared to crops of quinoa grown in different pedological conditions.

By statistical analysis of morphological and productive traits of the two species of alternative grains raised on fertile and moderately degraded lands in Vojvodina, it was determined that the differences obtained by comparing the amount of biomass and grain yield of buckwheat in different pedological conditions were significantly less than the differences observed for these traits in the case of quinoa. It was the opposite result when it comes to the height of the specimens of these two species, but not to a significant extent since there are only small differences between the values of the coefficient of variation. According to the literature, the growth of buckwheat is mostly influenced by climatic conditions [13, 28], primarily the water regime, while the location has less impact on the average plant height, although it is expected to be slightly greater on fertile rather than poor soil [25]. On the other hand, it is reported for quinoa that, apart from genotype (variety), location has a significant influence on plant height variation [26]. When it comes to the grain yield, weather conditions have the greatest impact on buckwheat yield in the plains, while soil conditions do not significantly affect buckwheat production, although it is understandable that grain yield is slightly higher in more favorable soil conditions than in other locations [13, 28]. The yield of buckwheat depends mostly on the amount of precipitation in the initial phenophases of development [25]. In contrast, although the literature states that quinoa can adapt well to unfavorable climate and soil conditions and can show high tolerance to frost, drought, and soil salinity [19] and that it can be grown in all regions, with very small variations in grain yield [13], the grain yields obtained in trials in different pedological conditions indicate that quinoa yield depends on chemical and physical properties of soil [10], as well as other environmental factors [26], primarily moisture and temperature [6], and to a lesser extent on genotype [26]. Since multivariate analysis (PCA), as well as CA, in this paper showed that crops of buckwheat, compared to crops of quinoa, are less morphologically and productively differentiated in relation to the location (land) in Vojvodina, it can be argued that the results testify in support of the aforementioned claims expressed in the literature.

The results of the research presented in this paper, which include analysis of variability of morphological and productive characteristics of quinoa and buckwheat, as well as their comparative productivity in different pedological conditions of Vojvodina, with the aim of determining the possibility and sustainability of the production of these crops outside their native ranges, suggest that the successful and sustainable production of quinoa and buckwheat as high-quality food is also possible in areas outside their native ranges and can be sustainable in the conditions of currently prevailing climatic conditions in the region. Also, the hypothesis was confirmed that moderately degraded land can be used for successful and sustainable production of high-value food, with small variations in grain yield, where preference should be given to buckwheat because its production on such land has proven more successful than the production of quinoa. These findings are in accordance with the claims stated in the literature, according to which buckwheat is not demanding in terms of soil, so it can be successfully grown on poorer mediums [29], and high and stable grain yields can be achieved [25]. Despite the fact that significant variations in yield parameters were found in trials conducted in Serbia, the yield of buckwheat grain was generally satisfactory, which is why this species is considered to thrive in the agroecological conditions of Serbia [13].

Buckwheat has a significant role in the diet of the population of northern and northeastern Europe, eastern Asia, and North America [29]. The total area under buckwheat in the world in 2014 was about 2,113,000 ha [24], and in 2017 it increased to 3,940,526 ha [28], with a tendency to grow. The largest producers are China (34.25%), Russia (32.24%) and Ukraine (11.46%) [24]. Buckwheat is grown for its achenes, which, when hulled, have great nutritional value. The phytochemical composition of buckwheat from the nutritional aspect is higher compared to the small grains and millet grains, which is expressed in terms of quantity, as well as quality, the content of proteins, vitamins, minerals, phytosterols, and antioxidants [15]. The content of amino acids in buckwheat (162.46 g/100 g of proteins) is higher than in quinoa (125.37 g/100 g of proteins) [10]. It belongs to the group of plants suitable for the production of high biological value food [29], and it is recommended to add its flour to bakery and confectionery products from other cereals to increase the nutritional potential of food and thus improve the health status of a population [15]. However, the production of this field crop in Serbia has been neglected, partly due to the widespread opinion that buckwheat is the food of the poor [28]. It is cultivated only in small areas, mainly in the hilly and mountainous region of southwestern Serbia [24]. Growing this crop is potentially very profitable for agricultural producers in Serbia, especially in the regime of organic production and in combination with beekeeping, since buckwheat is not only an important crop but also a honey-bearing species. It is also a desirable crop species in terms of sustainable ecological food production, bearing in mind that its production technology contributes to a favorable physical structure and soil conservation, and better biological balance in the environment [28]. It also has agro-technical importance, because as a dense sowing crop, it covers the soil well and controls weeds. It can absorb phosphorus from hard-to-reach forms and prevent its leaching into deeper soil layers and underground watercourses [29]. In the production of buckwheat, the average yield depends on the sowing density, with preference given to the average sowing density (120 grains/m$^2$) [30] and the "Novosadska" variety which is superior to other buckwheat varieties [24]. Buckwheat should be harvested to 80% seed ripening as the optimum harvest stage [16]. It was estimated [28] that its production has the potential to significantly contribute to the rural development of Serbia; however, it is necessary to support producers, because potential benefits cannot be expected in the short term.

## CONCLUSIONS

Based on the results presented in this paper, the following conclusions can be drawn:

1. Efficient and sustainable production of quinoa and buckwheat, as high biological value foods, is possible in areas outside their native ranges;
2. Quinoa and buckwheat production in Vojvodina (northern Serbia) is sustainable in the currently prevailing climate conditions of the region;
3. Moderately degraded land can be used for sustainable production of high-value food without prior application of agroameliorative measures, whereby preference is to be given to buckwheat which was more productive on such land than quinoa.

These results can serve as a starting point for further research and elaboration of this important issue. Their scientific and practical significance lies in proposing possible solutions to the problem of establishing sustainable production of high-quality food, as well as meeting the needs of modern society for an ecological approach to the food supply.

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**Received:** **22.03.2022**
**Accepted:** **21.08.2022**



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