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Introduction and adaptation of quinoa (*Chenopodium quinoa* Willd.) cultivars in Krasnodar region of Russia

Abstract

Quinoa (*Chenopodium quinoa* Willd.) is a cultivated plant of the Amaranthaceae family of Peruvian origin with high nutritional value. The Krasnodar region of Russia is a region with favorable climatic conditions for growing quinoa. The studies were carried out on the basis of Quinoa Center LLC, located in the Novokubansky district of the Krasnodar Territory. Four quinoa varieties were used as research material: Blanca de Juli, White Peru, Salcedo, the local variety Seva (included in the State Register of the Russian Federation in 2017) served as the standard. Various morphological parameters of plants were assessed and phenological observations were carried out.

The results showed statistically significant differences between varieties in plant productivity. The White Peru variety responded positively to the new conditions and was introduced without irrigation. The productivity of the panicle was on average 100 g, for the standard variety Seva - 70 g. In the dynamics of the ontogenetic development cycle of four quinoa varieties, it was established that the optimal sowing time in the conditions of the Krasnodar Territory is May. The tested varieties were also assessed for grain quality. In the conditions of the Krasnodar region they showed good results, thanks to selection for white grain and panicle uniformity. However, not all of them can be adapted, since they need constant watering and for late-ripening varieties autumn rains negatively affect their yield. The local early ripening variety Seva is of interest to Peru. In Peru, the main problem reducing production is low yield caused by frost in the Puno Peru region. The Seva variety reaches phenological phases: the beginning of panicle formation (R6), panicle formation (R7), flowering (R8) and full panicle ripening, physiological maturity (R12) and due to its early ripening it avoids frost. Therefore, the Seva variety can be recommended for sowing in the Puno-Peru region, since it has a gene pool that provides cold resistance but this requires detailed study. In general, to optimize the introduction of quinoa in Russia further research on adaptability in the Krasnodar region is necessary.

Keywords: quinoa, yield, variety, introduction, unfavorable climate

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Интродукция и адаптация сортов квиноа (*Chenopodium quinoa* Willd.) в Краснодарском крае России

Abstract

Киноа, или квиноа (*Chenopodium quinoa* Willd.) – культурное растение семейства Амарантовые перуанского происхождения с высокой пищевой ценностью. Краснодарский край России представляет собой регион с благоприятными климатическими условиями для выращивания киноа. Исследования проводили на базе ООО "НПО Квиноа центр", расположенном в Новокубанском районе Краснодарского края. В качестве материала для исследований использовали четыре сорта киноа: Blanca de Juli, White Peru, Salcedo, стандартом служил местный сорт Сева (включен в Госреестр РФ в 2017 году). Оценивали различные морфологические параметры растений, проводили фенологические наблюдения.

Результаты показали статистически значимые различия между сортами по продуктивности растений. Сорт White Peru положительно отреагировал на новые условия, и его удалось интродуцировать без орошения. Продуктивность метелки у него составила в среднем 100 г, у стандартного сорта Сева – 70 г. В динамике онтогенетического цикла развития четырех сортов киноа установлено, что оптимальным сроком посева в условиях Краснодарского края является май. Испытанные сорта были оценены также по качеству зерна. В условиях Краснодарского края они показали хорошие результаты, благодаря отбору при селекции на белое зерно и однородность метелки. Однако не все из них можно адаптировать, поскольку они нуждаются в постоянном поливе, и на позднеспелых сортах осенние дожди негативно отражаются на их урожайности. Местный раннеспелый сорт Сева представляет интерес для Перу. В Перу основной проблемой, снижающей производство, является низкая урожайность, вызванная заморозками в регионе Пуно-Перу. Сорт Сева достигает фенологических фаз: начала образования метелки (R6), формирования метелки (R7), цветения (R8) и полного созревания метелки, физиологической зрелости (R12) и за счет своей раннеспелости уходит от заморозков. Поэтому сорт Сева можно рекомендовать для посева в регионе Пуно-Перу, так как у него есть пул генов, обеспечивающий холодоустойчивость, однако это требует детального изучения. В целом, для оптимизации внедрения киноа в России необходимы дальнейшие исследования адаптивности в Краснодарском крае.

Ключевые слова: киноа, урожайность, сорт, интродукция, неблагоприятный климат

Introduction

Quinoa (*Chenopodium quinoa* Willd.) in its geographical center of origin, Peru, is distinguished by the genetic diversity of cultivated varieties suitable for any high-altitude climate, plateaus or valleys, as well as on the coast of the country [1]. It is an annual dicotyledonous species belonging to the subfamily Amaranthaceae. Quinoa is an Andean grain crop recognized as an ally of global food security due to its high nutritional value. However, the globalization of quinoa production entails problems for countries of origin. Farmers face a scenario of new problems and competitors [2]. In comparison with to traditional staple food crops quinoa has remarkable resistance to abiotic stress and is highly nutritious, uniquely balanced, and can therefore be an important crop for food security and nutritional adequacy [3].

Peru is the world's leading exporter and producer of quinoa, according to reports from the Ministry of Agrarian Development and Irrigation [4]. The largest quinoa-producing region in Peru is the city of Puno, where production is affected by the climate problem associated with frost. The main exporting country is Peru, with important exports from Bolivia and Ecuador; other countries that also produce Quinoa are the United States, Germany, Denmark, France, India, Italy, Kenya, Mexico, Sweden and the United Kingdom [4]. Quinoa (*Chenopodium quinoa* Willd.) is an organically managed crop. However, quinoa globalization entails challenges to the countries of origin in increasing organic management areas [5]. Therefore, it is necessary to improve the varieties in adverse climates. The cultivation of quinoa is still not very developed in the world except for its countries of origin leaving many parameters to be studied [6].

Compared to traditional staple food crops, quinoa has remarkable resistance to abiotic stress and is highly nutritious, uniquely balanced, and high in nutrients, and can therefore be an important crop for food security and nutritional adequacy. Due to the wide range of flavonoids and phenolic acids that quinoa possesses, they position it as a potential "nutraceutical" or "Functional food remedy", so its consumption contributes to the health and well-being of consumers and at the same time reduces the risk of non-communicable diseases due to its antioxidant, anti-inflammatory and anti-proliferation activity [7]. Quinoa contains about 16% protein. More related studies are needed to confirm particular properties of quinoa in relation to soil type, for example, observed locality-related differences in protein content [8].

Quinoa can tolerate a variety of environmental conditions, as well as long periods of drought and high salinity [9]. The genus includes about 250 species [10]. Both the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) rank it as a unique product because of its highest nutritional value [11]. However, the seed husk contains toxic compounds called saponins. These are secondary metabolites belonging to the group of glycosides formed by sugars (glucose, galactose and rhamnoses) associated with aglycone. Saponins are mainly concentrated on the outside of the grain layers, their concentration ranges from 0.01% to 5% per dry weight. The cleaning of the seed to remove the saponin is carried out by washing it for 15 minutes [12]. Quinoa was classified by saponin concentration into: sweet with saponin content less than 0.11% and bitter with the content of more than 0.11%, since they provide bitter taste [12]. In a research carried out in Argentina using different methods of extraction of oleanolic acid (OA) saponins in quinoa, the conclusions were that sweet quinoa has a concentration of less than 0.11% saponin oleanolic acid (0A) [13].

On the other hand, this species is classified into five main agro-ecological groups according to edaphic and climatic requirements, which corresponds to the quinoa at sea level, plateaus, jungles, inter Andean valleys and highlands [14].

The panicle has measurements of varying lengths of 15-70 cm. It is usually found at the top of the plant and at the top of the branches. It has a main shaft, secondary axes and tertiary axes. Given the shape and position of the glomeruli (flower groups), they are divided into amaranthiform, glomerular and intermediate. In the amaranthiform group, the glomeruli are directly inserted into the secondary axis, and the glomeruli have an almost rectangular shape, very similar to the fingers. In the glomerulata type, the glomeruli are located on the tertiary axis, which it derives from the secondary axis and takes on a rounded appearance, like beads of rosaries. In the intermediate type, the glomeruli has an indeterminate shape (between rectangular or rounded). The length of the secondary and tertiary axes determines whether the inflorescence can be weak, intermediate or compact; the last feature has to do with the size of the grains, with the smallest being those that form in a compact panicle [11].

Quinoa has a high nutritional value, adaptability to various agroecological conditions (genetic plasticity), resistance to soil salinization, resistance to extreme temperatures and resists water stress with low water availability in addition to expressing good results of adaptability to extreme climatic and soil conditions, which allowed the colonization of unproductive areas [15]. The protein content in quinoa varies between 8-22 g/100 g d. w., being closely close between the values of wheat and oats while those of rice, corn and barley are lower [16].

The flowers remain open for a period of 5 to 7 days, and because they do not open once at a time, it has been determined that the duration of flowering is 12 - 15 days. This indicates that the fruit containing grain can reach 2.66 mm in diameter depending on the variety, the perigonium covers the seed and easily comes off when rubbed [17].

Adaptability was acquired by evolutionary processes that included interbreeding with (Chenopodium carnosulum), hence its resistance to salinization; with (*Chenopodium petiolare*) to tolerate drought, and with (*Chenopodium pallidicaule*), its frost resistance [18].

Its vegetative period can vary from 90 to 240 days; it has an adequate development, with precipitation falls per year from 200 to 280 mm; it adapts to any soil texture and pH levels between 4.5 and 9.0 [19].

For the development of the research project in the area of introduction and adaptation of new varieties of quinoa we used the data on soil type and climate provided by the Ministry of Agriculture of Russia. The nutritional and biological properties were determines in quinoa that has been cultivated in different parts of the world during the last two decades and the potential of side stream processing of quinoa by-products in various industrial sectors [20].

The reports suggest prospects of quinoa grain inclusion in the daily diets of people and the application of their active compounds in the food industry [21].

The aim of the present investigation was the suitability evaluation of 4 promising varieties of quinoa (*Chenopodium quinoa* Willd.) of Peruvian origin in the climatic conditions of the Krasnodar region. The objectives of the research were to assess drought resistance with irrigation treatments and through the yield from each plant and to assess the vegetation period of each variety.

Material and Methods

Studies were conducted (to adapt and evaluate varieties to quinoa) during 2022 at the experimental site of the Quinoa Center, located in the farm of Novokubansk, Krasnodar Territory, Russia (45°06 N 41°03' E) in the North Caucasus. Its height is 149 meters above sea level. A random block design was used to determine the yield per plant (grain weight) of varieties of quinoa (*Chenopodium quinoa* Willd.). In 2022, the scientific experiment focused on the study of introduction and adaptation. Four varieties of quinoa were used as research material: Blanca de Juli, White Peru, Salcedo. The local variety Seva served as standard.

Seva is a variety of Russian selection. The height of the plants is about 220 cm. When ripe, the stem acquires a straw-yellow color with a pink tint. The ripe panicle is spear-shaped, 60-65 cm long, medium density, yellow-orange in color. Seeds are disc-shaped, beige. Weight of 1000 seeds is 3.4-3.5 g. The average yield in the conditions of the Krasnodar Territory is 41.7 c/ha. The growing season is 111-112 days. Biological characteristics: during the growing season plants are sensitive to frost, in the initial stages they are demanding moisture. The periods of flowering and ripening are extended in time (up to 30 days each). After the formation of the main panicle, the plants are resistant to drought. The main direction of use is the processing of seeds into cereals and flour for food purposes (according to the State Register of Selection Achievements of the Russian Federation).

The experimental design consists of 4 varieties with 3 blocks with 3 repetitions to determine the month of sowing quinoa and 3 treatments. (In total of 36 experimental units). To achieve the highest number of factorization in the experimental units irrigation varieties were applied. The treatments included: 1) watering at each vegetative stage; 2) watering every month; 3) no irrigation. Creating the largest possible number of randomization. 15 plants were collected in the 4 varieties.

The method consists of evaluating the panicle yield of each variety (60 quinoa plants). The data obtained were subjected to statistical analysis using analysis of variation (ANOVA) The comparison of mean values with the statistical box model was also used (graph) and Duncan's Multiple Range with software: Statistical Package S.A.S. (Statistical Analysis System) trial version. Critical differences were worked out using LSD at 5% level of significance in order to determine the statistical difference between varieties.

Determination of the optimal sowing date was carried out on May, June and July. Sowing was carried out with a distance between the rows of 80 cm and 60 cm between the plants. The number of seeds per unit was 10 kg/ha, from 5 to 8 seeds per stroke; covering it to a depth of 3 to 5 cm from soil moisture; with rain watering. The minimum of fertilizers was applied with a foliar fertilizer of Extra Action N: Nitrogen – 20% Organic nitrogen – 3%. Humic acids (humates) –3%. Organic matter – 12% in July to all the blocks.

The main characteristics of the soil of the experimental site in the Kuban are presented in Table 1. Mean month's temperature and precipitation value are recorded in Table 2.

Table 1. The characteristics of the soil of the experimental site in the Kuban. Krasnodar

Humus content	Hydrolytic acidity	Hydrolysable nitrogen	Phosphorus	Potassium
6%;	9.8 mg-eq/100 g	2.1 mg/100 g	3.1	17.8 mg/100g

Table 2. Mean month's temperature and precipitation during the vegetation period 2022 in Krasnodar region

Month	Temperature, °C	Precipitation, mm
May	15	157
June	24	62
July	30	0
August	25	37
September	19	69

The genetic selection of quinoa was carried out under the new environmental conditions using Physiological model of generation of yield determination with variables (rainfall), and (temperature). Using Excel diagrams the assessment of the relationship between climate and physiological maturity of the grain was achieved.

Height of the plant and panicles weight were measured in different stages of development. The taxonomic key for the Morphological identification of the varieties was made: color of the panicle in the period of physiological maturity, panicle shape, panicle density, type of growth, number of panicles per plant (Table 4).

Results and Discussion

The evaluated results of the panicle weight of the 4 quinoa varieties are presented in Table 3. They presented statistically significant differences between varieties 2 and

Table 3. Yield components in the 4 varieties of quinoa (Chenopodium quinoa Willd.)

Cultivar	Weight of 1000 seeds, (g)	Number of random samples (60), plants	Yield per plant, (g)	Vegetative cycle, (days)	Grain color, % phenotype
"Blanca de Juli"	2.2	15	80-100	160	White 90%
"White Peru"	3.7-4.0	15	100	130	White 98%
"Salcedo"	3.1-3.7	15	80	145	White 90%
"Seva", st.	2.8-3.1	15	70	120	White 70%

4, where variety 2, name: "White Perú" provided a yield of 100 grams/panicle, and variety 4, name: "Seva" recorded a yield of 70 grams/panicle (Table 3).

The varieties represented as 1 and 3 obtained physiological maturity of 145 and 160 days respectively, therefore, they are late varieties; represented 24 percent of the plant population in the experimental design (Table 4).

ated into the vegetative phase (V) and it is strickly important to differentiate each of the varieties the reproductive phase (R).

The beginning of the reproductive stage:

Panicle formation (R6). This phase is described as follows: An inflorescence with abundant meristematic tissue and abundant small leaves covering the panicle.

Table 4. Comparative characteristics of the quinoa variety (Chenopodium quinoa Willd.)

Parameter in physiological maturity (R12)	“Blanca de juli”	"White Peru"	“Salcedo”	"Seva", st.
Physiological maturity, days	160	130	160	120
Plant height, m	1.60	1.70	1.70	1.60
The length of the panicle, cm	30.0-35.0	34.0-40,0	35.0	30.035.0
Phenological cycle	Late variety	Semi early	Late variety	Early variety
Color of the panicle in the period of physiological maturity	White	White	White	White 70%
Panicle shape	Glomerular.	Glomerular.	Amarant form	Glomerular
Panicle density	Intermediate	Compact	Intermediate	Compact
Type of growth	Simple	Simple	Grassy	Grassy
Number of panicles per plant	1	1	1	1

Seeds were sown in the second week of May 2022, with a rainfall of 49 mm. and mean temperature of 15°C. Cultivar "White Perъ" demonstrates physiological maturation in August. The harvest of this new variety “White Perъ” was obtained successfully in all the experimental blocks. The aim of the study was to evaluate promising varieties of quinoa (*Chenopodium quinoa* Willd.) of Peruvian origin. We have shown that the habitat change influences some of the formation of quinoa grains.

All four varieties have reached 95% of their physiological maturity.

The study assessed the ontogenetic cycle allowing to identify each phenological phase in relation to other varieties. It is also important to present a botanical study of all the morphological characteristics of the 4 varieties (Table 4).

The physiological maturity and phenological cycle of quinoa was between 120 to 160 (Table 4). Quinoa has a defined phenological phase and very well differenti-

Formation of panicles (R7). This phase is described as follows: With a clear observation of the spreading inflorescence, glomeruli of flowers develop.

Beginning of flowering (R8). This phase is described as follows: When the apical hermaphroditic flower opens, showing individual stamens.

Flowering (R9). This phase is described as follows: it is

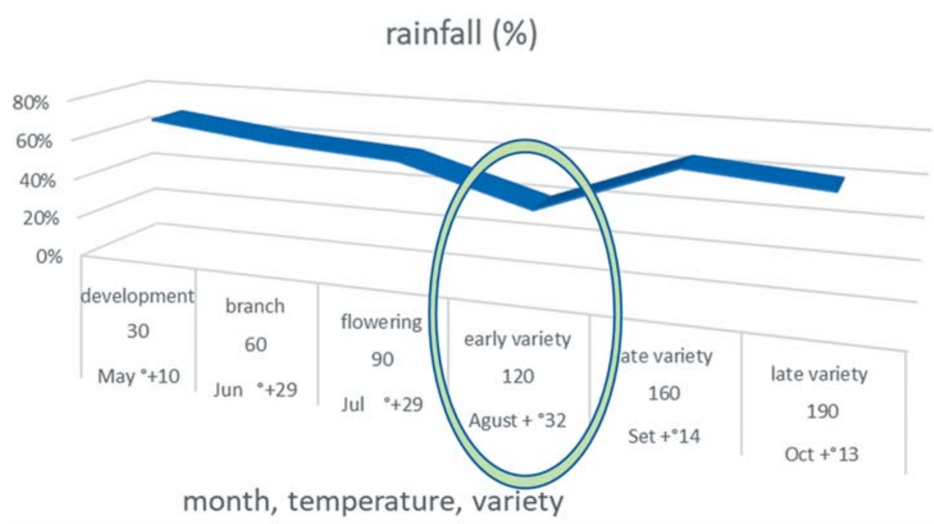

Fig.1. Physiological model of generation of yield determination of 4 varieties of quinoa (Chenopodium quinoa Willd.)

possible to distinguish between hermaphroditic and pistil flowers. The type of panicle for each variety can be determined with a percentage. For example, there are varieties that have 60% more male flowers than female ones.

Milk grains (R10). When the fruits are in the glomeruli of the panicle, when pressed, they burst and secrete a milky liquid.

Pasty grain (R11). When pressed, the fruits acquire a white paste-like consistency.

Physiological maturity (R12). When the fruit becomes hard to the touch, the grain can be harvested in a maximum of a week.

Physiological model of generation of yield determination of 4 varieties of quinoa (*Chenopodium quinoa* Willd.). Figure 1 shows that the critical point is month (August), against the factor of precipitation, the study shows that the vegetative period affects the phases: milk grain (R10), paste grain (R11), from 3 varieties: "Salcedo", "Blanca de juli", "White Perъ". The study found the critical grain formation point of a local variety "Seva": physiological maturity (R12) at 120 days, which means that it is highly adapted.

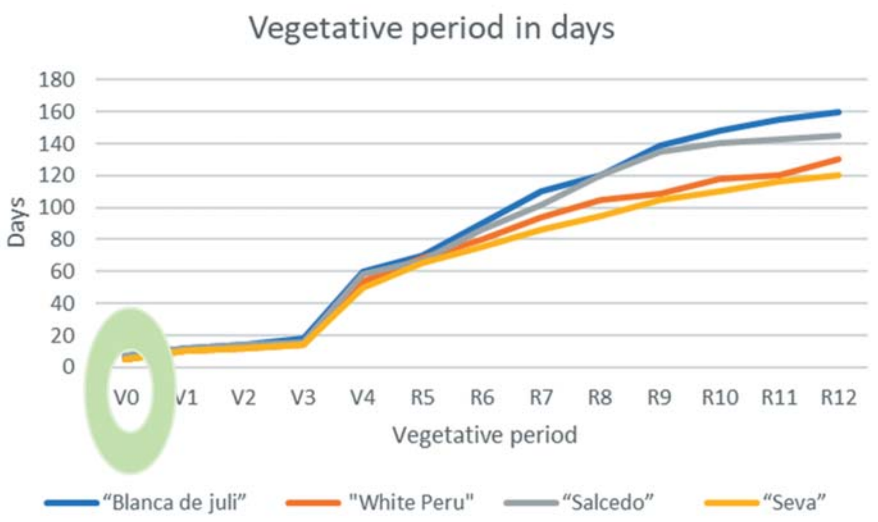

Fig. 2. Planting date and growing season of 4 varieties of quinoa (Chenopodium quinoa Willd.)

There are climatic factors that lead to the death of flowers. It is important not to lose flowers. Flowering (R9). Biological factors affecting the quinoa are fungal diseases, especially in late varieties where biological control methods are always recommended. Yield depends on the number of grains filled with starch. Pasty grain (R11).

Anticipating the sowing a day before the rain is an advantage at the seed germination stage V0 for all 4 varieties quinoa. The water requirements are different for each variety at the stages: appearance of true leaves (V2), four true leaves (V3), six true leaves (V4), branch height (V5), beginning of panicle formation (R5). Quinoa has a well differentiated vegetative period in the vegetative phase (V) and the reproductive phase (R). For example, each variety has a different behavior at the: Panicle formation (R6). This phase requires water for its adaptation because the metabolism of the photosynthates in the formation of grain is necessary to coincide with the rains. This explains the adaptation of early varieties in the Krasnodar climate "White Peru" with 130 days and "Seva" with 120 days. Date of sowing and phenology are presented in Figure 2. (The optimal sowing month is May). Seed germination V0, this critical moment should be solved in advance, using well-tilled soil since quinoa seeds are sown at a depth of 3 to 5 cm. The critical point at this stage is the strong heat of the sun, where the soil surface has the formation of crusts or layers of clay that prevent the emergence of seeds. The seeds to germinate are highly effective with humidity and being in contact with little water would be lost because they do not reach the surface, and on the other hand, the strong radiation prevents their development of cotyledonal leaves, therefore it is necessary to sow in a good percentage of rain.

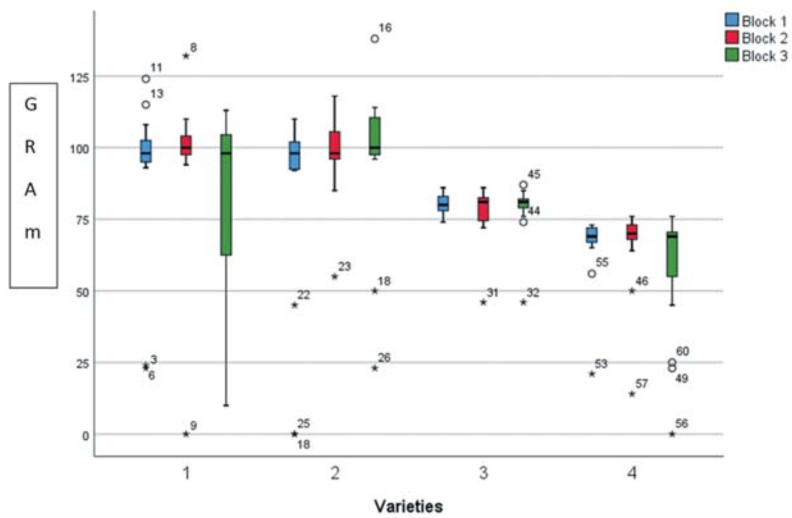

Fig. 3. Statistical description of the box of four quinoa varieties. The experimental design consists of 4 quinoa varieties: (1) cv. "Blanca de Juli"; (2) cv. "White Peru"; (3) cv. "Salcedo"; (4) cv. "Seva". With 3 blocks and with 3 repetitions to determine the month of sowing quinoa and 3 treatments. Block 1: seeds were sown 3 times (May, June, July) and irrigation in each vegetative stage (treatment 1). Block 2: Seeds were sown 3 times (May, June, July) and watering every month (treatment 2). Block 3: Seeds were sown with 3 times (May, June, July) without irrigation (treatment 3).

Frost damage provides fruit necrosis; due to frost the grain formation in the panicle stops. Corresponding to the stages: milk grain (R10), pasty grain (R11) and physiological maturity stage (R12) of late varieties. This frost problem is solved by selecting only the early varieties.

Furthermore, the lowest samples determine the mortality of the plants and are outside the lower quartiles; on the contrary, the upper limits are samples with high yields.

Statistically significant differences in panicle weight between early cultivars were demonstrate: cultivar "White Peru" recorded 100 grams/panicle, and cultivar "Seva" 70 grams/panicle (Fig. 3). And they are early varieties because the harvest was obtained at the end of August.

In the genetics of quinoa there are two behaviors in physiological maturation, so they can be activated with early maturation genetics or activated with late maturation genetics; it is known that the genetic behavior depends where seeds were sown in relation to the sea level altitude (100 at a 4000 m.a.s.l.) The present results demonstrated similar to the level near the sea, on the coast of Peru. Grain yield of "White Peru" was 95 grams on the coast of Peru. In the mountains of Peru the yields of cv. "White Peru" is 50 g.

Conclusion

Cultivar "White Peru" recorded the yield of 100 grams/panicle per plant while cv "Seva" demonstrated the grain yield 70 grams/panicle per plant. These are the varieties indicated for adaptation to the climate of the Krasnodar region. The use of fertilizers is not important since it is necessary to express the phenotypic and genotypic characteristics in the new climatic environment and compare it with the place of origin of Peru. The morphological characteristics of all 4 varieties tested, were selected according to the quality of the grain. They are excellent for introduction due to the selection of white grain and the uniformity of the panicle. But not all of them may be adapted because they need constant watering. The local variety has a genetic "gene pool" of interest to Peru because it is adapted to the harsh climate and avoids frost because it is an early ripening variety.

The main problem that reduces production is the low yield caused by frost in the Puno-Peru region, for this reason the scientific article attempts to overcome the problem of 4 varieties in adverse climate conditions and compare with the standard the adaptation of the local variety Seva which reaches phases phenological phases of: the beginning of the formation of a panicle (R6), panicle formation (R7), flowering (R8) and full ripening in the panicle, physiological Maturity (R12). In late ripening varieties, the rains from October to December negatively affected yields. Therefore, it is also recommended to sow this cv. "Seva" in the Puno-Peru region, since it has a pool of genes already expressed in frost conditions. In a whole, further investigations on quinoa adaptability in Krasnodar region are necessary to optimize quinoa introduction in Russia.

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