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YIELD PERFORMANCES OF QUINOA FOR LEAVES UNDER IRRIGATION AND FERTILISATION REGIME

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Abstract

Quinoa is a pseudo-cereal native to South America, known mainly for seeds. In recent years, studies and research have begun to be done on leaves, as it is known that in the area of origin, some local populations used as vegetables. The aim of the research is to evaluate the effect of fertilisation and irrigation on the growth and production of two quinoa varieties (Vikinga and Puno), in order to introduce them on the Romanian economic market. The experience was organised in vegetation pots, in 42 variants, in the greenhouse. The obtained results show that the species is suitable for cultivation in protected areas, under the influence of factors: cultivar, fertilisation and irrigation. The highest amount of leafy mass was obtained by Vikinga variety under biological fertilisation irrigated with 75% of water from substrate capacity (SC) positively correlated with the leaf area and the number of leaves. The irrigation with a rate of 75 % of the substrat capacity obtained the best results, compared to the regimes of 50 % and 100 % of the substrate capacity.

***Key words**: quinoa, cultivar, fertilisation, irrigation.*

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is considered a pseudo-cereal, native from Latin America. The species still has a strong traditional imprint, even if new modern practices appear, due to studies conducted at the University of Colorado (USA) and in Europe (Pedersen at al., 2015; Mujica A., 2001).

The cultivation of the species was largely abandoned with the arrival of the Spanish conquerors, who replaced the quinoa plant with cereals brought from Europe (wheat and barley), much more productive at that time. The quinoa plant is currently grown throughout the Andean region, in the USA, in Europe, Asia and Africa (Bazile et al., 2016; Mazoyer et al., 2006).

Quinoa is a plant grown mainly for its edible seeds, with a high degree of digestibility (Asao et al., 2010). Also, the leaves can be eaten as a substitute for spinach, in various dishes, well known in the area of origin (Stoleru et al., 2021; Vitanescu, 2020).

The nutritional value of quinoa leaves is special, quinoa is a very interesting food, being a precious source of protein, vitamins and minerals (FAO, 1992).

According to the Food and Agriculture Organization of the United Nations (FAO), quinoa can assure the global food security due to its high nutritional qualities as well as tolerance to various abiotic stresses including salinity (FAO, 2013).

Due to the fact that it can be grown in the fields, as well as in tunnels and greenhouses, quinoa can ensures also a sustainable production throughout the year (Stoleru et al., 2022; Pedereson et al., 2020).

An intresting scientific papers highlight the unique nutritional value of quinoa leaves, both in terms of nutritional and anti-nutritional. One of this work brings to the fore the insignificant role of anti-nutritive substances (such as oxalates, saponins and trypsin inhibitors), content of three cultivars of quinoa (Titicaca, Puno and Vikinga), grown for its leaves and is subject to density of 7.7, 3.2 and 1.6 mil plants/ha and times of sowing by April 17. The content of precious minerals (Fe, Zn, Na and K) was significant depends on the cultivar compared to Mg and Ca, whose insignificant

values did not depended on treatments (Stoleru et al., 2019).
In this respect, the efforts of researchers are mainly focused on the following research directions, namely: drought resistance, salinity and the defence mechanisms of the quinoa species against abiotic stressors - drought and salinity.
Another research about abiotic stress such drought and salinity have been conducted to evaluate the effects of Biochar in relieving stress independent drought or salinity. The pots experience was conducted in the climate-controlled chamber to investigate the effects of Biochar on growth, physiology and yield of quinoa under independent and combined drought and salinity stress (Yang, 2020).
The results showed that Biochar, as an amendment to the soil, has the potential to improve the soil and alleviate the stress of drought and salinity (Yang, 2020).
A study was conducted in 2014 on the effect of organic and chemical fertilisation on the yield and quality of quinoa biomass and green amaranth biomass, intended for animal feed in the Mediterranean area, during the dry season bibliografie (Papastylianou et al., 2014)
The results shwoed the superiority of quinoa species over the green amaranth in terms of plant height and dry substance, while there were no significant differences in nutritional value and biomass between the two species.
Compost fertilisation showed higher values in terms of biomass quality in quinoa cultivation, while chemical fertilisation gave better results in amaranth cultivation (Papastylianou et al., 2014).
The aim of our research was to establish the upper and lower limits, which the quinoa species could tolerate without significantly affecting the growth and development, being subject to the influence of the irrigation and fertilisation factors.

MATERIALS AND METHODS

The research was carried out in a greenhouse of Iasi University of Life Sciences (IULS), Romania, during March 29 to April 07. The goal of study was to evaluate quinoa response to different regimes of fertiliser and irrigation doses under controlled conditions of temperature (16-18ºC/20-22ºC), humidity (70-75%/60-65%) and natural light (13/11 hours).
The biological material used was represented by quinoa seeds of two cultivars Puno and Vikinga. The seeds were kindly provided by Quinoa Quality ApS (Denmark) (Figures 1-3).

Figure 1. View of quinoa seeds

All plants were harvested at 35 days after sprouting (DAS) and all leaves were collected for further measurements and determinations.

Figure 2. View of quinoa leaves at the harvest time

Soil substrate was peat Kekkila® (300 l x 2) mixed with Orgevit® (3.00 kg/m^3) and Perlite® (3.00 kg/m^3).
Kekkila® is a substrate for seeding production, with pH adjusted to 5.5-5.9, with fertilised formula “starter” NPK 14-16-18 + ME.
Orgevit® is a fertiliser that can be used in organic crops and contains micro and macro-elements.
Perlit® results from volcanic rock with a granular structure and high porosity, produce rapid rooting of seedlings and seed germination, ensuring a harmonious development of plants.

The fertilisers used were represented by biologic fertiliser Micoseed MB® and chemical fertiliser KSC® II, in different quantities.
To test the influence of type of fertilisations on plant growth were used the following amounts:

- Biological fertilisation: 500 g/m^3 (F1); 1000 g/m^3 (F2); 1500 g/m^3 (F3) - Micoseed MB®;
- Chemical fertilisation: 1000 g/m^3 (F4); 2000 g/m^3 (F5); 3000 g/m^3 (F6) KSC®.

For the watering of the substrate, water was used in different percentages quantities 50%/75%/100% of substrate capacity.

Figure 3. View from the greenhouse of Iasi University of Life Sciences (IULS), Romania

The experience was organised in vegetation pots (2700 cm^3 capacity). Corresponding to the proposed factors resulted 42 variants, of 5 replicates, 8 plants for each repetition.
For statistical analyses the data are expressed as the means ± standard deviation (SD). The analysis of variance (ANOVA) was used to see the influence of cultivar, fertilisation and irrigation on the number of leaves, chlorophyll pigments, leaf surface and green leaf biomass of quinoa.
To determine the significant differences between treatments were established by using Tukey's post hoc test with a degree of confidence of 95% ($p \leq 0.05$), using a SPSS ver. 21.

RESULTS AND DISCUSSIONS

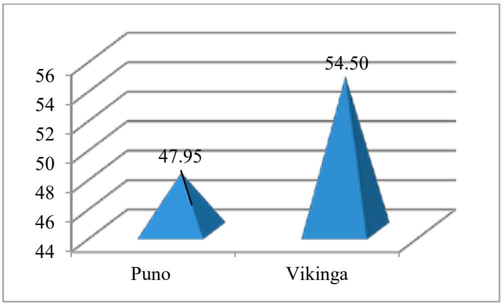
The results on the influence of the cultivar on the number of leaves, photosynthetic pigments, leaf surface and production are presented in Table 1.

Table 1. The influence of the cultivar on the morphological and photosynthetic indicators

Cultivar	No. of leaves	Pigments (CCI)	LAI (cm²)
Puno	110.3 ± 2.6 b	11.9 ± 0.3 b	1454.5 ± 69.2 ns
Vikinga	120.5 ± 2.34 a	13.4 ± 0.2 a	1447.0 ± 43.8 ns

*The values represent the mean ± standard error. The lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a - represents the highest value; ns - nonsignificant).

The number of leaves is the character which recorder significant differences between the two variants, these being 110.4 leaves for the Puno and 120.6 leaves for Vikinga, the difference between the two cultivars is 10.2 leaves.
Also, the data from Table 1 show that the maximum value of the chlorophyll index recorded is 13.4 CCI in the case of the Vikinga cultivar and the minimum value is 11.9 CCI in the case of the Vikinga cultivar.
Regarding the study of influence of the cultivar on the leaf area, the data show that there are no significant differences, obtaining close value (1454.5 cm²-1447.0 cm²). Also, between the two cultivars there were no significant differences in production (47.95 leaves-54.50 leaves), as in Figure 4.



*The values represent the mean ± standard error.

Figure 4. The influence of the cultivar on the production

The results of the influence of the fertilisation regime on the number of leaves, photosynthetic pigments, leaf surface and production are presented in Table 2.

Table 2. The influence of the fertilisation on morphological and photosynthetic indicators

Fertilisation	No. of leaves	Pigments (CCI)	LAI (cm²)
NF	133.5 ± 6.5 a	10.1 ± 0.2 b	1597.3 ± 91.5 ab
F1	127.6 ± 3.2 a	9.9 ± 0.2 b	1723.3 ± 53.0 ab
F2	124.4 ± 1.4 a	9.9 ± 0.2 b	1908.3 ± 86.8 a
F3	116.7 ± 3.5 a	10.5 ± 0.2 b	1533.1 ± 64.1 b
F4	131.5 ± 3.7 a	15.2 ± 0.5 a	1613.2 ± 76.1 ab
F5	93.2 ± 3.9 b	17.1 ± 0.7 a	1062.3 ± 75.2 c
F6	81.2 ± 2.8 b	15.8 ± 0.9 a	718.0 ± 71.7 d

*The values represent the mean ± standard error. The lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a - represents the highest value; ns – nonsignificant, V-Vikinga, NF – control, F1- 500 g/m³ MB, F2 –1000 g/m³ MB, F3- 1500 g/m³ MB, F4 –1000 g/m³ KSC I, F5 –2000 g/m³ KSC I, F6- 3000 g/m³ KSC I)

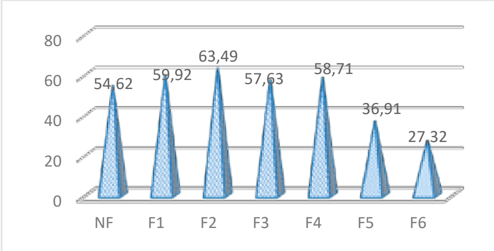
The effects of fertilisation on the growth of quinoa plants are shown in Table 2, where significant differences are observed between control and chemical variants, where the value varied from 133.5 leaves to 81.2 leaves, for the character number of leaves.

Also, higher values (127.6 leaves and 124.4 leaves) are observed for the biologically fertilised variants F1 - F2, compared to the chemically fertilised variants F5 and F6. There was a significant difference of 50.3 leaves between chemically fertilised F4 and F6 variants. It can be concluded that the plants suffer from a higher concentration of chemical fertiliser > 2000 g/m³ KSC I.

The data of Table 2, showed that in the case of chemical fertilisation F5, the photosynthetic pigments have the highest chlorophyll index of 17.1 CCI. We can also notice significant differences between biologically and chemically fertilised variants. Between biological variants F1-F3 there is a significant difference, also between the chemically fertilised variants F4-F6.

For the character of the leaf surface the values varied from 718.0 cm², in case of the variant F6, to 1908.3 cm², in case of the variant F2.

Regarding the production, the results presented in Figure 5, in the case of biological fertilisation with Micoseed MB®, variants F1-F3, recorded higher values compared with control. The maxim value obtained was 63.4g, of variant F2, due to the effect of microorganisms introduced into the crop substrate, this being also the maximum value registered within the experimental variants. Also, the variant F4 registered a higher value than the control.



*The values represent the mean ± standard error; NF – control, F1- 500 g/m³ MB, F2 –1000 g/m³ MB, F3- 1500 g/m³ MB, F4 –1000 g/m³ KSC I, F5 –2000 g/m³ KSC I, F6- 3000 g/m³ KSC I

Figure 5. The influence of the fertilisation regime on the production

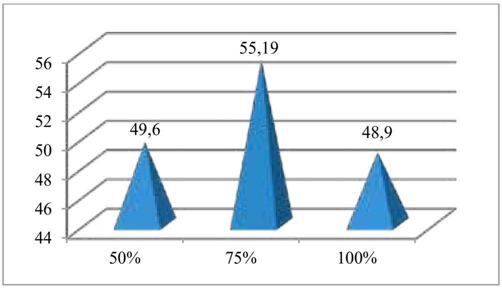
The variant F5 and F6 with the minim values of the measured biometric indicators- number of leaves, leaf surface and production, shows significant differences compared with all the other variants. This is explained by the fact that the concentration > 2000 g/m³ affects the growth and producion of quinoa plants.

The results on the influence of the irrigation factor on the number of leaves, photosynthetic pigments, leaf surface and production are presented in Table 3.

Table 3. The influence of the irrigation on morphological and photosynthetic indicators

Irrigation	No. of leaves	Pigments (CCI)	LAI (cm²)
50%	112.9 ± 2.7 ns	12.6 ± 0.2 ns	1666.0 ± 40.2 a
75%	118.9 ± 2.7 ns	12.3 ± 0.5 ns	1419.9 ± 68.1 b
100%	114.5 ± 2.7 ns	13.0 ± 0.3 ns	1266.4 ± 43.1 b

*The values represent the mean ± standard error. The lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a - represents the highest value; ns - nonsignificant); The values represent the mean ± standard error.



*The values represent the mean ± standard error; 50%, 75%, 100% irrigation regime

Figure 6. The influence of the irrigation regime on the production

The variants benefited from gradual irrigation starting from 50%, 75% and 100% of the substrate capacity (Figure 6).

For the character of the leaf surface, there are significant differences, the higher value of 1666.0 cm² recorded by irrigation variant of 50%, determines significant differences compared to the other two types of irrigation (75% and 100%). The results on the combined influence of factors (cultivar x fertilisation x irrigation) on the number of leaves, photosynthetic pigments, leaf surface and production are presented in Table 4.

The results on the combined influence of factors on the number of leaves, in the case of the quinoa species, we can notice that the results varied depending on the cultivar, fertilisation and irrigation regime, obtaining the following values for the number of leaves - from 62.00 leaves, in the case of the the chemical variant Vikinga - F6, to 144.60 leaves in the case of unfertilised Vikinga, with an irrigation rate of 75%.

Table 4. The influence of the combined factors on the number of leaves

Treatment	**Irrigation regime**		
Interaction	50%	75%	100%
P x NF	116.60 ± 11.58 abcdefg	118.00 ± 15.62 abcdefg	116.00 ± 10.70 abcdefg
P x F1	127.20 ± 5.61 abcdef	131.00 ± 7.91 abcde	120.20 ± 6.22 abcdef
P x F2	125.60 ± 3.98 abcdef	118.60 ± 2.99 abcdefg	112.40 ± 7.08 abcdefgh
P x F3	117.20 ± 2.85 abcdefg	121.20 ± 13.58 abcdef	116.40 ± 6.11 abcdefg
P x F4	117.40 ± 4.97 abcdefg	131.80 ± 6.68 abcde	140.80 ± 11.58 abc
P x F5	87.80 ± 5.94 defgh	83.80 ± 8.96 efgh	83.60 ± 8.53 efgh
P x F6	78.00 ± 18.94 fgh	68.20 ± 7.96 gh	86.40 ± 11.33 defgh
V x NF	161.60 ± 10.83 a	144.60 ± 11.71 ab	144.40 ± 10.21 ab
V x F1	131.00 ± 8.88 abcde	132.60 ± 6.82 abcde	123.80 ± 3.76 abcdef
V x F2	124.60 ± 2.99 abcdef	125.80 ± 6.97 abcdef	139.60 ± 9.68 abc
V x F3	112.40 ± 0.75 abcdefgh	132.40 ± 6.07 abcde	101.00 ± 20.53 bcdefgh
V x F4	134.20 ± 7.56 abcde	135.80 ± 4.85 abcd	129.40 ± 9.81 abcdef
V x F5	85.80 ± 7.00 defgh	126.40 ± 6.59 abcdef	92.20 ± 9.17 cdefgh
V x F6	62.00 ± 5.83 h	95.40 ± 3.93 bcdefgh	97.40 ± 11.12 bcdefgh

*The values represent the mean ± standard error. The lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a - represents the highest value; ns – nonsignificant, V-Vikinga, NF – control, F1- 500 g/m^3 MB, F2 –1000 g/m^3 MB, F3- 1500 g/m^3 MB, F4 –1000 g/m^3 KSC I, F5 –2000 g/m^3 KSC I, F6- 3000 g/m^3 KSC I)

Table 5. The results on the combined influience of factors on the chlorophyll pigments (CCI)

Treatment	**Irrigation regime**		
Interaction	50%	75%	100%
P x NF	10.68 ± 0.80 defgh	9.84 ± 0.19 gh	9.96 ± 0.84 gh
P x F1	9.60 ± 0.32 gh	9.94 ± 0.16 gh	9.68 ± 0.52 gh
P x F2	9.72 ± 0.31 gh	9.44 ± 0.62 gh	10.92 ± 0.48 cdefgh
P x F3	10.78 ± 0.97 cdefgh	9.74 ± 0.31 gh	9.74 ± 0.45 gh
P x F4	14.82 ± 1.55 abcdefgh	13.80 ± 1.77 bcdefgh	14.20 ± 1.08 abcdefgh
P x F5	15.10 ± 0.53 abcdefgh	14.96 ± 1.61 abcdefgh	15.32 ± 1.59 abcdefgh
P x F6	14.32 ± 0.55 abcdefgh	12.74 ± 3.24 bcdefgh	15.00 ± 1.44 abcdefgh
V x NF	9.42 ± 0.24 h	10.46 ± 0.91 fgh	10.30 ± 0.38 fgh
V x F1	10.02 ± 0.77 gh	10.00 ± 0.44 gh	10.72 ± 0.62 cdefgh
V x F2	9.76 ± 0.73 gh	10.36 ± 0.54 fgh	9.76 ± 0.52 gh
V x F3	10.5 ± 0.34 efgh	9.74 ± 0.37 gh	12.54 ± 0.93 bcdefgh
V x F4	15.22 ± 0.84 abcdefgh	16.16 ± 0.59 abcdefg	17.22 ± 1.96 abcde
V x F5	19.18 ± 1.35 ab	17.44 ± 1.48 abc	20.82 ± 1.60 a
V x F6	17.40 ± 1.35 abcd	18.76 ± 3.09 ab	16.88 ± 1.98 abcdef

*The values represent the mean ± standard error. The lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a - represents the highest value; ns – nonsignificant, V-Vikinga, NF – control, F1- 500 g/m^3 MB, F2 –1000 g/m^3 MB, F3- 1500 g/m^3 MB, F4 –1000 g/m^3 KSC I, F5 –2000 g/m^3 KSC I, F6- 3000 g/m^3 KSC I)

The physiological character represented by the chlorophyll pigments varied from 9.42 CCI, in the case of control Vikinga cultivar, with on irrigation rate of 50%, to 20.82, in the case of chemically fertilised Vikinga cultivar, F5 variant, with on irrigation rate of 100%.

Table 6. The results on the combined influience of factors on the leaf surface (cm²)

Treatment	Irrigation regime		
Interaction	50%	75%	100%
P x NF	1983.40 ± 261.95 abcd	1704.00 ± 209.22 abcdefghi	1079.20 ± 238.09 defghijkl
P x F1	2489.60 ± 127.93 a	1602.4 ± 200.96 abcdefghij	1202.00 ± 144.96 cdefghijkl
P x F2	2462.80 ± 138.37 ab	1560.80 ± 147.83 abcdefghij	1806.20 ± 214.55 abcdefg
P x F3	2072.60 ± 210.16 abc	1312.80 ± 268.70 cdefghijkl	1313.80 ± 93.48 cdefghijkl
P x F4	1959.40 ± 277.8 abcde	1603.60 ± 147.47 abcdefghij	1428.20 ± 58.87 cdefghijk
P x F5	1579.20 ± 144.71 abcdefghij	775.60 ± 186.08 ijkl	719.40 ± 106.77 jkl
P x F6	825.00 ± 282.63 hijkl	486.60 ± 63.77 l	579.40 ± 144.7 kl
V x NF	1700.60 ± 89.19 abcdefghi	1546.80 ± 91.58 bcdefghij	1570.20 ± 227 abcdefghij
V x F1	1698.60 ± 105.65 abcdefghi	1818.60 ± 55.42 abcdefg	1529.00 ± 148.97 cdefghij
V x F2	1814.00± 113.58 abcdefg	1716.20 ± 139.62 abcdefgh	2090.20 ± 103.31 abc
V x F3	1535.40 ± 30.16 bcdefghij	1868.00 ± 161.19 abcdef	1096.20 ± 227.09 defghijkl
V x F4	1636.60 ± 54.78 abcdefghij	1423.00 ± 82.48 cdefghijk	1628.60 ± 235.68 abcdefghij
V x F5	986.00 ± 109.10 fghijkl	1419.20 ± 100.17 cdefghijkl	894.40 ± 175.35 ghijkl
V x F6	580.80 ± 85.82 kl	1042.20 ± 104.74 efghijkl	794.00 ± 234.86 hijkl

*The values represent the mean ± standard error. The lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a - represents the highest value; ns – nonsignificant, V-Vikinga , NF – control, F1- biologic/ 500 g/m³ MB, F2 – biologic/1000 g/m³ MB, F3- biologic/1500 g/m³ MB, F4 – chemical /1000 g/m³ KSC I, F5 – chemical /2000 g/m³ KSC I, F6- chemical/3000 g/m³ KSC I)

Regarding the influence of the factors on certain morphological characteristics, the differences can also be observed, from 486.60 cm², in the case of the chemical Puno variant F6, with the irrigation rate of 100%, to 2489.60 cm², in case of chemical Puno variant F1, with the irrigation rate of 50%. The values of the leaf surface decrease gradually with the increase of the quantity of water administered for the three irrigation regimes.

The conclusion is that the irrigation regime is negatively correlated with the leaf area.

Table 7. The results of the technological factors on the yield (g)

Treatment	Irrigation regime		
Interaction	50%	75%	100%
P x NF	47.42 ± 5.19 abcdefgh	47.34 ± 10.56 abcdefgh	45.48 ± 3.82 abcdefgh
P x F1	58.22 ± 2.91 abcdefg	63.00 ± 6.80 abcdef	48.41 ± 2.86 abcdefgh
P x F2	61.87 ± 3.81 abcdef	64.75 ± 3.79 abcde	54.05 ± 5.78 abcdefg
P x F3	57.74 ± 1.76 abcdefg	57.73 ± 9.99 abcdefg	64.14 ± 5.23 abcde
P x F4	53.20 ± 3.03 abcdefg	60.08 ± 3.60 abcdef	50.98 ± 3.05 abcdefgh
P x F5	35.41 ± 3.59 cdefgh	31.06 ± 7.25 efgh	35.00 ± 6.12 cdefgh
P x F6	24.26 ± 9.22 gh	17.65 ± 4.46 h	29.26 ± 9.94 fgh
V x NF	54.61 ± 2.93 abcdefg	64.81 ± 4.54 abcde	68.08 ± 9.90 abcd
V x F1	59.42 ± 2.44 abcdef	74.90 ± 2.21 a	55.61 ± 6.60 abcdefg
V x F2	63.94 ± 5.53 abcde	67.10 ± 5.53 abcd	69.21 ± 4.83 abc
V x F3	59.18 ± 2.56 abcdef	71.55 ± 6.82 ab	35.45 ± 11.48 cdefgh
V x F4	67.00 ± 1.53 abcd	63.78 ± 3.62 abcde	57.23 ± 5.94 abcdefg
V x F5	34.35 ± 4.53 defgh	50.50 ± 4.97 abcdefgh	35.16 ± 7.12 cdefgh
V x F6	17.82 ± 4.24 h	38.35 ± 3.57 bcdefgh	36.54 ± 13.96 cdefgh

*The values represent the mean ± standard error. The lowercase letters represent the results of the Tukey test for $p \leq 0.05$ (a - represents the highest value; ns – nonsignificant, V-Vikinga , NF – control, F1- 500 g/m³ MB, F2 –1000 g/m³ MB, F3- 1500 g/m³ MB, F4 –1000 g/m³ KSC I, F5 –2000 g/m³ KSC I, F6- 3000 g/m³ KSC I)

For the production, only the aerial part of the plant was studied (the edible part). The values varied from 17.82 g in the case of the chemical Vikinga cultivar, variant F6 with the irrigation

rate of 50%, to 74.90 g, in case of the Vikinga cultivar – F1, with the irrigation rate of 75%. The cultivar that obtained the best results is Vikinga, as in the case of the researches done by Vitanescu (Vitanescu et al., 2019).
In terms of chlorophyll pigments and production it can be notice that 100% irrigation regime favored positively.

CONCLUSIONS

1. Vikinga is the cultivar that obtained the best results, but the differences are not significant compared to Puno, in terms of production, which means that the species is suitable for leaves cultivation.
2. The highest yield of quinoa leaves was obtained from chemical fertilisation, under the influence of the fertilisation regime, followed by the biological, which is recommended for the sustainable crops.
3. The irrigation at a rate of 75% of the substrate capacity obtained the best results. In the case of overirrigation the results obtained were much lower than in case of 50% and 75% irrigation regime. It can be concluded that the species has mechanisms of resistance and adaptation to water stress.
4. The combined factors Vikinga, chemical fertilisation 500 g/m^3 with 75% of the substrate capacity gave the best results.
5. The result regarding all the factors shows that the specie is suitable for cultivation in protected areas.

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