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RESPUESTA DE LOS BROTES DE QUINOA A ILUMINACIÓN CON LUCES LED SOBRE LOS PARÁMETROS DE CRECIMIENTO Y EL CONTENIDO FENÓLICO TOTAL

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RESUMEN

Los ecotipos de quinoa representan una fuente de aminoácidos y fitoquímicos bioactivos como los compuestos fenólicos. El consumo diario de este tipo de alimentos de origen vegetal se ha asociado a una reducción de la incidencia de diversas enfermedades. En este sentido, la aplicación de elicitores como LED (diodos emisores de luz) o combinaciones de luces LED puede mejorar la acumulación de fitoquímicos bioactivos induciendo estrés oxidativo en la planta. Se evaluó el efecto de la iluminación LED sobre los parámetros de crecimiento, la producción de compuestos bioactivos y la capacidad antioxidante de los brotes de quinua. Los ecotipos de quinua Real Negra, Roja y Chañu fueron cultivados bajo luces LED con longitudes de onda blanca, azul y roja a diferentes porcentajes de intensidad combinada: C1: 40-50-30, C2: 5-100-100 y C3: 15-100-50 y se analizaron los efectos de la iluminación LED después de 5 días, evaluando el peso fresco, peso seco e índice de crecimiento de los brotes, así como su contenido fenólico total (TPC) y actividad antioxidante. El experimento se realizó en una cámara de crecimiento bajo condiciones controladas de temperatura, humedad, luz y fotoperiodo. Los parámetros de crecimiento mostraron diferencias significativas en peso fresco, peso seco y tasa de crecimiento en condiciones de luz. Los compuestos fenólicos presentaron valores entre 62,2 y 276,1 mg de equivalentes de ácido gálico g-1 peso seco de la muestra. La capacidad antioxidante osciló entre 191,0 y 1.433,9 mmol equivalentes Trolox g-1 peso seco de la muestra. La combinación de longitudes de onda LED (blanco, azul y rojo) en la combinación de porcentaje de intensidad C1: 40-50-30 mostró los incrementos más significativos en los parámetros de crecimiento, concentración fenólica total y capacidad antioxidante en los brotes de quinoa.

ABSTRACT

Quinoa ecotypes represent a source of amino acids and bioactive phytochemicals such as phenolic compounds. The daily consumption of this type of plant-based food has been associated with a reduction in the incidence of various diseases. In this sense, the application of elicitors such as LED (light-emitting diodes) or combinations of LED lights can improve the accumulation of bioactive phytochemicals by inducing oxidative stress in the plant. The effect of LED lighting on growth parameters, production of bioactive compounds, and antioxidant capacity of quinoa sprouts was evaluated. The quinoa ecotypes Real Negra, Roja, and Chañu were grown under LED lights with white, blue, and red wavelengths at different percentages of combined intensity: C1: 40-50-30, C2: 5-100-100 and C3: 15-100-50 and the effects of LED lighting were analyzed after 5 days, evaluating fresh weight, dry weight, and growth index of sprouts, as well as their total phenolic content (TPC) and antioxidant activity. The experiment was conducted in a growth chamber under controlled conditions of temperature, humidity, light, and photoperiod. Growth parameters showed significant differences in fresh weight, dry weight, and growth rate under. light conditions. Phenolic compounds had values between 62.2 and 276.1 mg gallic acid equivalents g^{-1} dry weight of the sample. Antioxidant capacity ranged from 191.0 to 1,433.9 mmol Trolox equivalents g^{-1} sample dry weight. The combination of LED wavelengths (white, blue, and red) at intensity percentage combination C1: 40-50-30 showed the most significant increases in growth parameters, total phenolic concentration, and antioxidant capacity in the quinoa sprouts.

CAPITULO I

INTRODUCCIÓN GENERAL

La demanda de cultivos con alto contenido nutricional está creciendo no solo en las regiones desarrolladas, sino también en las regiones en desarrollo del mundo. Dentro de estos cultivos destaca la Quinua (*Chenopodium quinoa* Willd.), planta herbácea anual perteneciente a la familia Amaranthaceae (Elsohaimy et al., 2015) quien, debido a su extraordinario valor nutricional y aceptación pública como un alimento alternativo, aumentó su consumo en los últimos 10 años. En la actualidad, la quinua se cultiva principalmente en Bolivia, Chile, Colombia, Ecuador y Perú (Dakhili et al., 2019), sin embargo, su cultivo se ha extendido a países como Australia, Canadá, China, Inglaterra y otros (Aziz et al., 2018; Hu et al., 2017).

Este pseudo-cereal (Carciochi et al., 2016; Dakhili et al., 2019) es una planta anual, ginomonoica, de tallo erguido y hojas alternas (Bhargava et al., 2006), y que produce frutos aquenios (granos de quenopodos), de diversos colores, diámetro 1,5 - 4 mm (Gordillo-Bastidas et al., 2016).

Los granos de quinua clasificados según su color pueden ser amarillos, blancos, rojos y negros (Tang et al., 2015). Estos granos contienen entre 12%

y 21% de proteína (Garcia-Parra et.al, 2020) y son cultivados en el altiplano y zonas áridas de América del sur.

La quinua Real Negra es originaria de Bolivia y se cultiva en el municipio de Salinas de Garci Mendoza en el departamento de Oruro. Los granos de este ecotipo contienen entre 1,67 y 3,08 g kg^{-1} de compuestos fenólicos totales con relación al peso seco, además, posee una elevada capacidad antioxidante (Tang et al., 2016). La quinua roja originaria de la región andina de Bolivia, Peru, Colombia y Ecuador, es uno de los ecotipos más utilizados en la producción. El ecotipo Chañu de origen geográfico en la comunidad de Pisalaca en Salinas de Garci Mendoza, generado de un cruzamiento genético no inducido, presenta una coloración parda rojiza con matices de pigmentación negra en sus granos, y es muy utilizado para la gastronomía local (Bonifacio et al., 2016). Estos cultivares son producidos a 3,782 m.s.n.m, en suelos salino-volcánicos, lo que le confiere un contenido nutricional único y una capacidad de adaptación a diferentes condiciones climáticas y edafológicas.

Por otro lado, las semillas de quinua no contienen gluten y poseen altos niveles de ácidos grasos, vitaminas, minerales, fibra dietética y aminoácidos (Abderrahim et al., 2015; Gómez-Caravaca et al., 2014; Pellegrini et al., 2018

Tang et al., 2015), son fuente de proteínas de alta calidad precursoras de péptidos bioactivos con actividad antioxidante (Sánchez-García et al., 2022) y contienen una gran variedad de compuestos bioactivos como carotenoides , vitamina C y compuestos fenólicos. Estos compuestos bioactivos actúan como protectores contra una gran variedad de enfermedades, particularmente cáncer, alergias, enfermedades inflamatorias, y puede reducir el riesgo de enfermedades cardiovasculares (Pereira et al., 2019). Todas estas propiedades están presentes en semillas, hojas, brotes y germinados de quinua (Lin et al., 2019; Liu et al., 2021; Paśko et al., 2008; Tang et al., 2016). Se ha evidenciado que la concentración fenólica total y la capacidad antioxidante aumenta con la germinación de semillas (Abderrahim et al., 2015; Carciochi et al., 2016; Enciso-Roca et al., 2021; Hu et al., 2017; Pellegrini et al., 2018; Tang et al., 2016), sin embargo, la concentración fenólica aumenta también con la exposición a diferente calidad, intensidad y fotoperiodo de luz (Fischer et al., 2017).

La luz es la fuente de energía esencial para la fotosíntesis en las plantas, su importancia radica en su efecto sobre el crecimiento y desarrollo de estas. La transducción de señales de luz involucra procesos bioquímicos de relevancia para la biosíntesis de compuestos secundarios (Costa et al., 2022) y en cambios fotomorfogénicos (Oh et al., 2022).

Los diodos emisores de luz (LED) constituyen en una fuente de luz fácilmente controlable por el investigador (Bian et al., 2015), permitiendo la manipulación de longitudes de luz aprovechables según el objeto de investigación. Se ha demostrado que las luces LED estimulan la acumulación de compuestos fenólicos en *Verbena officinalis L.* cultivada *in vitro*, con la exposición a diferentes cantidades y calidades de luz (Kubica et al., 2020). Los brotes de remolacha roja (*Beta vulgaris L.*) tratados con LEDs (rojo: azul-blanco/ 4:1) elevaron el contenido fenólico total (Oh et al., 2022). En cultivos de callos de *Ocimum basilicum* la aplicación de LEDs mejoró la producción de ingredientes biológicamente activos (Nadeem et al., 2019). En cultivos de brotes transformados de *Dracocephalum forrestii* la combinación con diferentes calidades de luz roja y azul permitieron mayor acumulación de compuestos fenólicos (Weremczuk-Jeżyna et al., 2021) como también en brotes de trigo sarraceno común (*Fagopyrum esculentum Moench*) (Hornyák et al., 2022).

Con base en estos antecedentes, el objetivo de esta investigación fue evaluar el efecto de diferentes combinaciones LED sobre el contenido fenólico total, capacidad antioxidante y parámetros de crecimiento, en germinados de tres ecotipos de *Chenopodium quinoa* Willd.

HIPÓTESIS

La iluminación con luces LED en espectros visibles azul, rojo y blanco combinados, influirá en los parámetros de crecimiento y aumentará el contenido de compuestos fenólicos totales y capacidad antioxidante en germinados *Chenopodium quinoa* Willd.

OBJETIVO GENERAL

Evaluar la combinación de distintas luces LED sobre los parámetros de crecimiento, contenido de compuestos fenólicos totales y capacidad antioxidante en germinados de tres genotipos de quinua.

OBJETIVOS ESPECÍFICOS

- Evaluar parámetros de crecimiento en germinados de quinua bajo el efecto de longitudes de onda azul, rojo y blanco.
- Determinar el contenido fenólico total en germinados de tres ecotipos de quinua iluminados con LED de diferente calidad.

  Determinar el efecto de luz LED de diferente calidad sobre la capacidad antioxidante en tres genotipos de quinua.

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CAPITULO II

RESPONSE OF QUINOA (CHENOPODIUM QUINOA WILLD) SPROUTS TO LED LIGHTING ON GROWTH PARAMETERS AND TOTAL PHENOLIC CONTENT.

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Abstract

Quinoa ecotypes represent a source of amino acids and bioactive phytochemicals such as phenolic compounds. The daily consumption of this type of plant-based food has been associated with a reduction in the incidence of various diseases. In this sense, the application of elicitors such as LED

(light-emitting diodes) or combinations of LED lights can improve the accumulation of bioactive phytochemicals by inducing oxidative stress in the plant. The effect of LED lighting on growth parameters, production of bioactive compounds, and antioxidant capacity of quinoa sprouts was evaluated. The quinoa ecotypes Real Negra, Roja, and Chañu were grown under LED lights with white, blue, and red wavelengths at different percentages of combined intensity: C1: 40-50-30, C2: 5-100-100 and C3: 15-100-50 and the effects of LED lighting were analyzed after 5 days, evaluating fresh weight, dry weight, and growth index of sprouts, as well as their total phenolic content (TPC) and antioxidant activity. The experiment was conducted in a growth chamber under controlled conditions of temperature, humidity, light, and photoperiod. Growth parameters showed significant differences in fresh weight, dry weight, and growth rate under light conditions. Phenolic compounds had values between 62.2 and 276.1 mg gallic acid equivalents g^{-1} dry weight of the sample. Antioxidant capacity ranged from 191.0 to 1,433.9 mmol Trolox equivalents g^{-1} sample dry weight. The combination of LED wavelengths (white, blue, and red) at intensity percentage combination C1: 40-50-30 showed the most significant increases in growth parameters, total phenolic concentration, and antioxidant capacity in the quinoa sprouts.

Keyworks: Fresh Weight, Dry Weight, Capacity Antioxidant, Photosynthetically Active Radiation.

INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd) is an annual species native to South America. It is an herbaceous, tetraploid, halophyte plant (Bazile et al., 2016) belonging to the family Chenopodiaceae and classified as a pseudo-cereal. The grain of quinoa has high contents of fatty acids, vitamins, minerals, dietary fibers, amino acids (Tang et al., 2016) and bioactive compounds (Lin et al., 2019). About 193 secondary metabolites have been reported in quinoa (Lin et al., 2019), among them, several phenolic compounds that are ubiquitous in this species (Zhang et al., 2020).

Sprouts are obtained from the grain of this pseudocereal (Bhargava et al., 2006; Dakhili et al., 2019; Gordillo-Bastidas et al., 2016) and, interestingly, the phenolic content increased with seed germination (Abderrahim et al., 2015; Carciochi et al., 2016; Fischer et al., 2017; Pellegrini et al., 2018), being the concentration of bioactive compounds in sprouts higher than in mature plants (Zhang et al., 2020). Twenty-nine phenolic acid analogues were identified in quinoa, including gallic acid, protocatechinic acid, cinnamic acid, and ferulic acid, which stand out for being present in sprouts (Lin et al., 2019). Therefore, nutritional and potential health benefits are attributed to quinoa sprouts, due to the increased availability of nutrients, as well as phenolic compounds and antioxidant capacity.

Studies on different species have evaluated the use of lights in the production of bioactive compounds. It was demonstrated that *Fagopyrum esculentum* Moench sprouts exposed to different qualities of LED light showed a higher accumulation of phenolic compounds (Hornyák et al., 2022a). In addition, higher antioxidant activity was evidenced in shoots of *Zea mays* L. (Xiang et al., 2022), as well as in shoots of *Brassica oleracea* varieties (Kim et al., 2006; Liu et al., 2016; Qian et al., 2016; Vale et al., 2015). In pea sprouts, it was observed that 585 nm LED light decreased the total phenolic content (Liu et al., 2016), and in soybean sprouts, exposure to LED light significantly enhanced antioxidant activity (Yuan et al., 2015). However, although there is research on the total phenolic content and antioxidant capacity of quinoa seeds, the effect of LED light sources on the accumulation of these secondary compounds in quinoa sprouts has not been studied so far.

The aim of this work was to assess the relationship of different combinations of wavelengths and intensities of LED lights on growth parameters, phenolic compounds content, and antioxidant capacity in sprouts of three ecotypes of C. quinoa.

MATERIALS AND METHODS

Plant material

Seeds of *C. quinoa* cultivars Real Negra, Roja and Chañu (225g each) obtained from the agricultural farm of Pisalaca - Salinas de Garci Mendoza, Oruro – Bolivia and harvested in March 2022 were used. The seeds were sorted according to size and those with a diameter of 2.0 ± 0.5 mm were used. The average weight of 1,000 seeds was 4.59 ± 0.5g and the germination percentage was 98 ± 1 %.

Growth conditions

The experiment was conducted at the Phytochemistry laboratory, Faculty of Agronomy, Universidad de Concepción, Chile under controlled conditions. The growth chamber was set at 22 ± 2 ºC, 80 ± 2 % humidity, 16/8 hrs light/dark photoperiod, and 416.5 ± 12.7 µmol m^{-2} s^{-1} PAR intensity. The LED light source was a Titan Ready® 6 CREE Indoor LED illumination, with 3.5w CREE XPE LED diodes, and 40w Xpower COB chip.

Experimental design

The experiment consisted of nine treatments, resulting from the combination of three light conditions obtained with white, blue, and red wavelengths at different percentages of intensity C1: 40-50-30; C2: 5-100-100, and C3: 15-100-50, respectively, and three quinoa genotypes (Real Negra, Roja, and Chañu). The experimental design was completely randomized, with a factorial arrangement, five replications, and 45 experimental units.

Growth parameters

Seed sowing was performed according to ISTA (2016) recommendations for cereals. Five g of seeds were placed in sterilized glass Petri dishes of 14.5 cm diameter, using as substrate two layers of filter paper moistened with 20 ml of distilled water, and sealed with parafilm. Germination was carried out inside the growth chamber in the dark for 48 hours and then germinated seeds were exposed to the light treatments for 5 days. Sprout growth was evaluated as fresh weight (FW), dry weight (DW), and growth index (GI) determined as %GI=(FW2 - FW1)/FW2x100, where FW1 is the fresh weight of the plants at the beginning of the treatment and FW2 is the fresh weight after 5 days of light treatment. The sprouts were then collected and dried for 24 hours at 35 °C in an air force oven Binder ED 056 (BINDER GmbH, Germany). Weights were determined with a Precisa XR 205SM-DR balance (Precisa Gravimetrics AG, Switzerland).

Extraction and determination of antioxidants

For the extraction of antioxidants in grains and sprouts, 0.5 g of ground dry sample was used. The sample was treated with 5 ml of methanol/water/formic acid (25:24:1, v/v/v), placed in ultrasonic bath for 1 hour, and then allowed to stand at 4 °C for 24 hours. The next day it was again placed in ultrasound for 1 hour, centrifuged at 4,000 rpm for 5 minutes and the supernatant was collected.

Total Phenolic Concentration (TPC)

The Folin-Ciocalteu method (Singleton and Rossi, 1965) was used to determine the total polyphenol content. To each well of a plate was added 12 µL of Folin Ciocalteu 1N reagent, 42 µL of the sample, 162 µL of water, and finally 34 µL of 20% sodium carbonate solution. In the blank, the sample was replaced with the same volume of water. It was then allowed to stand for 2 hours in the dark. The absorbance of the samples was measured at 760 nm using a Synergy H1 hybrid multimode microplate reader (Biotek, Winooski, VT, USA). A calibration curve was obtained using gallic acid as a standard and the polyphenol content was expressed as milligram gallic acid equivalents per 100 g dry weight of the sample. Each sample was replicated twice.

Antioxidant capacity by DPPH assay

Free radical scavenging activity was determined by DPPH (2,2-Diphenyl-1-picrylhydrazyl) method adapted to a microscale according to Gu et al. (2019). The antioxidant capacity of DPPH was performed as follows: 50 µL of the extract and 200µL of the DPPH solution were added, shaken vigorously, and kept in the dark for 1 hour. The blank contained 250 µL of methanol. Finally, reading was performed at 515 nm on a microplate reader (Synergy H1 Microplate Reader Biotek, Winooski, VT, USA). Each sample was replicated twice and results were expressed as µmol Trolox 100 g^{-1} dry weight.

Statistical analysis

Normality and homocedasticity were performed to check the variance assumptions using the Shapiro-Wilk test and F test, respectively. Analysis of variance (ANOVA) and Tukey's multiple comparison of means tests were performed; differences were considered significant for $p < 0.05$. These analyses were performed with the statistical program InfoStat professional (Infostat, 2008). In addition, a principal component analysis (PCA) was performed to establish the relationships between genotypes, treatments and traits evaluated, using the XLSTAT Excel data analysis add-in. Data are presented as mean and standard error.

RESULTS AND DISCUSSION

Effect of LED lighting on Growth Parameters

The use of LEDs is a proven and viable alternative for lighting in the cultivation of plants under controlled environments (Massa et al., 2008) and the combination of red and blue LEDs is commonly used to increase growth and biomass production (Hornyák et al., 2022; Ma et al., 2021). In general, the fresh weight of the quinoa sprouts after 5 days under the different light conditions ranged from 14.73 to 30.90 g (Table 1). Among genotypes, the highest fresh weight was shown by the ecotype Real Negra, which was 12.6% and 27.8% higher than that achieved in Rojo and Chañu, respectively. A similar trend was observed for the other two growth parameters. The dry weight of the sprouts ranged from 1.72 to 3.65 g, with Selva Negra reaching significantly higher values than those obtained by the other two genotypes, where the dry weight decreased by 21 to 23.5 %. Meanwhile, the growth index was 3.1% and 12.4% higher in Selva Negra than in Rojo and Chañu, respectively. On the other hand, light conditions significantly affected growth parameters (Table 1). The highest fresh weight was obtained with the light treatment C1, which was 8.5 % and 34.3 % higher than that achieved in C2 and C3, respectively; all light treatments being statistically different from each other. A similar trend was observed for dry weight, which decreased by 1.3 % and 21.2 % in C2 and C3 compared to C1; however, the C1 and C2 treatments did not differ from each other. Meanwhile, growth rate decreased by 3.1 % and 12.4 % in C2 and C3, respectively, relative to C1, and the means in each condition were statistically different from each other. In general, fresh weight, dry weight and growth index tended to be higher in the C1 light conditions, although there were not differences in dry weight between C1 and C2; among genotypes, Real Negra had the highest values in the growth parameters, regardless of light treatment. Meanwhile the ecotype Chañu had the lowest values, specifically in light conditions C2 and C3.

With the use of LED lights, higher leaf growth rate values have been reported in *Valerianella locusta* compared to natural light (Wojciechowska et al., 2013). Although this study was carried out only under artificial conditions, it is noteworthy that the highest growth was achieved in the condition where the highest percentage of white light was used and enriched with intensity percentages of 50 and 30 % of blue and red light, respectively. In this study, fresh weight, dry weight, and growth rate were influenced by light quality, which has been previously reported by Hornyák et al. (2022) who using a combination of 53% red light, 25% blue light and 15% green light achieved the highest leaf biomass production in shoots of *Fagopyrum. esculentum*. The lower values of growth parameters recorded in the combinations C2 may be the fact that the red wavelength at high intensity inhibits biomass growth (Landi et al., 2020), whereas the highest values were found in C1 subject to the low intensity of the red light and a balance with blue, a more energetic spectral range.

Effect of LED on TPC

As has been previously reported, the total polyphenolic content increased with seed germination (Abderrahim et al., 2015; Carciochi et al., 2016; Fischer et al., 2017; Pellegrini et al., 2018) (Figure 1). The TPC in sprouts was higher relative to seed in all quinoa genotypes, and especially, in the light treatments C1 and C2. At C1 TPC increased by 225.9, 206.9 and 205.1 % in Real Negra, Roja and Chañu, respectively. There was an increase at C2 between 124.8, 176.7 and 99.9 %, and to a lesser extent at C3, which increases in TPC ranging from 84.0, 5.9 and 32.8 %, after five days under the light treatments.

In general, sprouts of Real Negra tended to show higher TPC respect to Roja and Chañu, regardless the light conditions and C1 tended to show higher values than C2 and C3, irrespective of the ecotypes. The different combinations of LED lights had different effects on the concentration of total phenols. The highest TPC was found in Real Negra grown under the C1 light condition with 276.05 mg AGE 100 g^{-1} DW, which was 100.7% higher than that obtained in the same genotype in the C2 condition, and 141.5 % higher than that obtained in C3 which did not differ from that found in Roja with the C1 and C2 light treatments. On the other hand, the lowest TPC was obtained in Roja and Chañu under de light condition C3 with 62.91 and 62.19 mg AGE $100g^{-1}$ DW, respectively.

The intensity, quality, and duration of light regulate the metabolism of higher plants (Zhang et al., 2020). Phenolics are secondary metabolites in plants and light has been shown to increase the TPC by enhancing photosynthesis as well as the phenylalanine pathway, which is associated with the synthesis of phenolic compounds (Qian et al., 2016). The synthesis of phenolic compounds was different among light conditions (Figure 1), which could be explained by different mechanisms of the phenylalanine ammonia lyase (PAL) regulation (Engelsma, 2022), a key enzyme in phenol synthesis, which is influenced by light controlling the accumulation and transformation of hydroxycinnamic acids. At the same time, the PAL reaction is strategically located at a branch point between primary and secondary metabolism. Thus, the reaction is a very important regulatory pathway in the formation of many phenolic compounds (Marchiosi et al., 2020). In addition, receptors in plants, represented by cryptochromes and phototropins, are also light sensors that presumably have been involved in TPC accumulation Studies showed that LED light can increase phenolic content in shoots (Lee et al., 2014; Paśko et al., 2009; Seo et al., 2015; Thwe et al., 2014).

Furthermore, the ratio of red and blue light influences the production of phenolic compounds a red/blue ratio of 1/3 can induce gallic acid synthesis up to 15-fold, increasing the phenolic content in *Ocimum basilicum* L. (Nadeem et al., 2019).

On the other hand, it is presumed that the lower phenol accumulation (Figure 1) is linked to a lower PAL concentration that could possibly be inhibited by an excess of blue wavelengths, which contain photons with more energy, in C2 and C3 conditions. These results differ in what reported by (Vaštakaitė et al., 2015) where in green basil total phenolic compounds increased with increasing proportions of blue and red light. However, in the same species, Tomomi Shiga et al. (2009) found that TPC increased with white light, like what was obtained in this study where the highest phenol production occurred in the C1 condition containing the highest proportion of white light.

Effect of LED on Antioxidant Capacity

Antioxidant capacity showed significant differences between the different light combinations and quinoa genotypes (Figure 2). Consistent with what was observed in TPC, the antioxidant activity of the sprouts was higher than that of the corresponding grain in each genotype. Previous studies in quinoa seeds have reported values of antioxidant capacity in the range of 7.38-12.40 mmol Trolox equivalente kg^{-1} DM (Vollmannová et al., 2013) and up to 38.84 mmol trolox kg-1 DW (Paśko et al., 2009). The highest antioxidant capacity was recorded in all LED combinations in the Real Negra (1433.9 µg Trolox g^{-1} DW), with increases of 138.1, 47.8 and 35.6% in C1, C2 and C3, respectively, with respect to the antioxidant activity of the seed; similar to the effect observed in this genotype for TPC, as phenols are potent radical scavengers (Melini and Melini, 2022). However, in Roja and Chañu, the effect of light was less consistent, showing Roja an opposite effect, with significant increases in antioxidant activity in C2 and C3 compared to C1, while in Chañu, under the C2 condition it increased by 613.3 compared to C1.

Naznin et al., (2016) indicate that antioxidant capacity decreased with higher proportions of red in cilantro, this may explain the decrease of antioxidants at C2 in Roja and Chañu. The antioxidant activity obtained here is significantly higher to that reported by Lim et al. (2019) who measured values of 87.55, 79.52 and 70.58 µg trolox g^{-1} DW in red, black, and white cultivars of quinoa.

In general, Real Negra stood out, showing higher averages regardless of the light condition and the three light combinations achieved significant increases in antioxidant capacity for the three quinoa ecotypes studied with respect to that found in grain. Considering that both red and blue light influence growth and synthesis of secondary metabolites in sprouts of quinoa through photochemical mechanisms and that the responses are genotype specific, the biomass production and their quality is defined by finding the optimal proportions of different wavelengths of light and growing conditions.

Principal Component Analysis

A principal component analysis (PCA) was performed to establish the relationship between genotypes and light treatments with growth parameters, TPC and antioxidant capacity (Figure 3). The first two components of the PCA explained 91.82% of data variability. The variables evaluated in quinoa sprouts samples exposed to different LED light combinations are plotted as linear vectors segmented from the origin and the circles show the location of each interaction (light combinations and ecotypes) with respect to each vector. A high correlation was observed between the C1-Real Negra interaction with respect to TPC and antioxidant capacity and, to a lesser extent, these traits were associated with C3-Real Negra and the relationship decreases in the C2-Real Negra interaction. In contrast, the C3-Roja and C2-Chañu interactions showed differences in terms of a presumed increase in total phenolic content and antioxidant capacity. Growth parameters were highly correlated with C1-Chañu, C1-Roja, C2-Roja and C2-Real Negra interactions, on the contrary C3-Chañu. In general, regardless of the light condition, the ecotype Real Negra showed the highest correlation in terms of total phenols, antioxidant capacity and growth parameters. It was followed by Roja ecotype, specifically, under the C1 and C2 light treatments. On the other hand, the genotype Chañu under the C2 and C3 light conditions showed lower values of association, but under the effect of the C1 combination it obtained higher values in terms of growth parameters.

CONCLUSIONS

The results of this study showed that growth as well as the polyphenol synthesis and antioxidant capacity of quinoa sprouts under different light conditions are species specific and a proper balance between different spectral ranges of light is required to improve growth, tpc production and antioxidant activity in the sprouts. the most positive effects were achieved in the selva negra ecotype and specifically in the treatment with the most balanced treatment between white, blue, and red light (c1; 40:50:30 %). in general, this light condition generated higher sprout growth and production of phenolic compounds, independently of the genotype, as well as a notable increase in antioxidant activity in selva negra. on the other hand, high red wavelength intensities decreased growth parameters in rojo and chañu ecotypes. although more quinoa genotypes and light conditions need to be studied, illumination with led lights may be a good strategy to improve the nutritional potential of quinoa sprouts due to increased phenolic concentration and antioxidant capacity.

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FIGURES AND TABLES

Table 1. Effect of LED lights in different combinations on growth parameters in quinoa sprouts.

		Fresh Weight (g)	Dry Weight (g)	Grow Index (%)
Ecotype (E)	Real Negra	28.19±1.1 a	3.28±0.1 a	81.83±0.7 a
	Rojo	24.65±1.3 b	2.59±0.2 b	78.79±1.2 b
	Chañu	20.36±1.6 c	2.51±0.1 b	73.30±2.0 c
Lighting (L)	C1	28.46±0.8 a	3.02±0.1 a	82.24±0.5 a
	C2	26.03±1.0 b	2.98±0.1 a	79.67±1.7 b
	C3	18.71±1.5 c	2.38±0.2 b	72.02±1.4 c
E x L	Real Negra-C1	30.51± 2.9 a	3.28±0.4 ab	83.49±1.6 a
	Real Negra-C2	30.90±1.7 a	3.65±0.3 a	83.68±1.6 a
	Real Negra-C3	23.16±1.6 bc	2.93±0.1 bc	78.33±1.6 b
	Rojo-C1	27.09±2.5 ab	2.73±0.2 bcd	81.40±1.9 a
	Rojo-C2	28.60±1.6 a	3.09±0.3 ab	82.41±1.6 a
	Rojo-C3	18.26±0.8 cd	1.72±0.2 e	72.57±1.3 c
	Chañu-C1	27.77±3.0 ab	2.93±0.2 bc	81.82±2.0 a
	Chañu-C2	18.59±2.4 cd	2.33±0.1 d	72.92±2.5 bc
	Chañu-C3	14.73±2.6 d	2.50±0.2 cd	65.18±6.1 d

White-blue-red LED combinations; C1:40-50-30 %; C2: 5-100-100 %, and C3: 15-100-50 %. All data were expressed as mean ± standard error of measurements. Values in a column followed by similar letter do not differ significantly ($p < 0.05$).

(source: own elaboration)

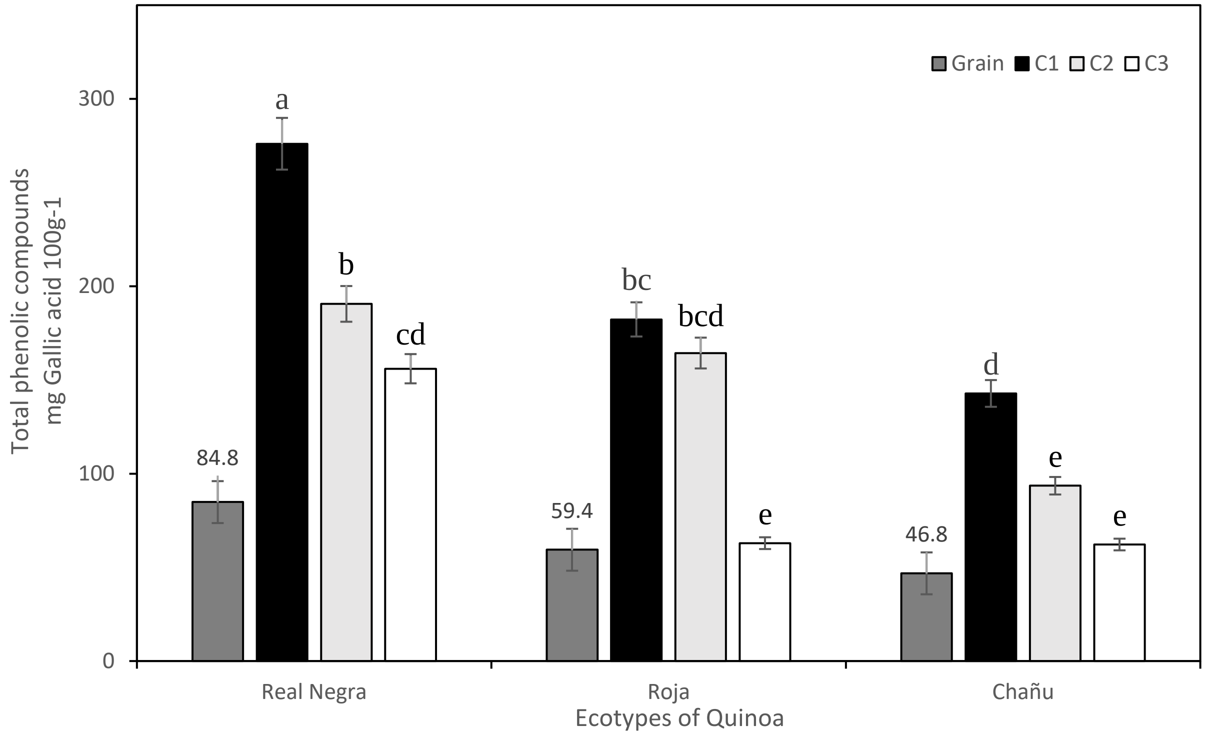

Figure 1. Effect of LED lights in different combinations on the concentration of total phenols in quinoa sprouts. Different letters indicate significant differences ($p < 0.05$). White-blue-red light combinations; C1:40-50-30 %; C2: 5-100-100%, and C3: 15-100-50%; Grain: initial grain value.

(source: own elaboration)

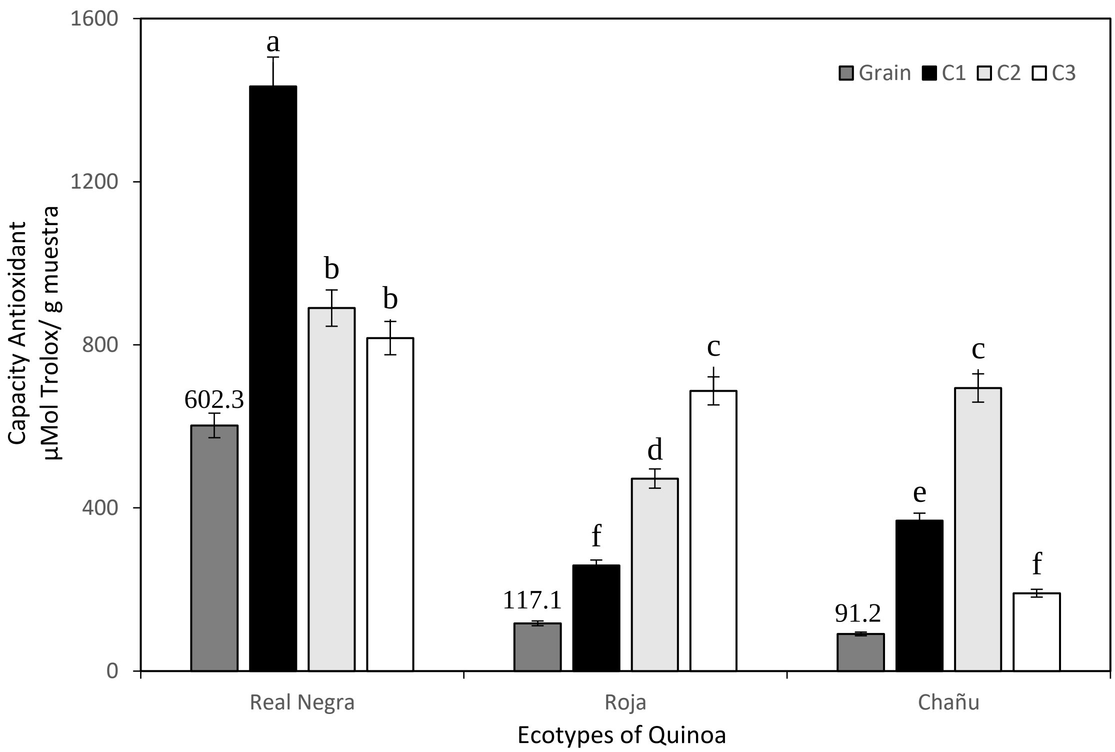

Figure 2. Effect of LED lights in different combinations on antioxidant capacity in quinoa sprouts. Different letters indicate significant differences (p <0.05. White-blue-red light combinations; C1:40-50-30 %; C2: 5-100-100 %, and C3: 15-100-50 %; Grain: initial grain value.

(source: own elaboration)

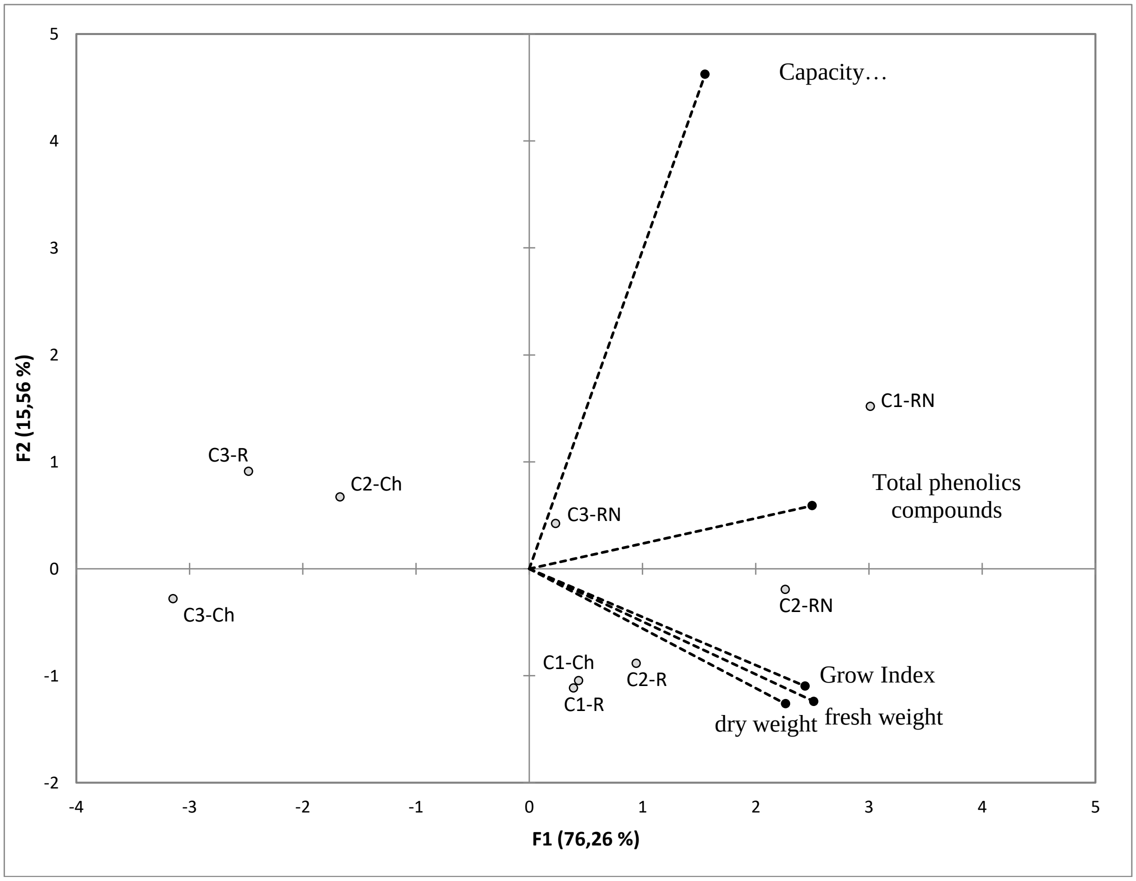

Figure 3. Principal component analysis (PCA) for quinoa discrimination based on fresh weight, dry weight, growth rate, total phenols, and total antioxidant capacity. The closer the points are to a particular variable, the higher the positive correlation. Combination of spectra LED light; White-blue-red combinations; C1:40-50-30 %; C2:5-100-100 %, and C3:15-100-50%. Ecotypes, RN: Real Negra, R: Rojo, and Ch: Chañu.

(source: own elaboration)

CAPITULO III

CONCLUSION GENERAL

Altos niveles de intensidad de luz roja disminuyeron los parámetros de crecimiento en los genotipos Chañu y Rojo, sin embargo, generó un crecimiento significativo en Real Negra. Por otro lado, un equilibrio entre luz blanca, azul y roja como en C1 40:50:30 %, respectivamente, mostró que la síntesis de compuestos fenólicos y la capacidad antioxidante en brotes fueron significativamente mayores respecto a la encontrada en granos de quinua, independientemente del genotipo estudiado.

Los efectos más positivos en cuanto a promoción del crecimiento, contenido de fenoles y actividad antioxidante fueron hallados, específicamente, en C1 con el ecotipo Real Negra. Además, se evidenció mayor concentración fenólica con C1, respecto a los ecotipos Roja y Chañu a diferencia de las combinaciones C2 y C3. Las combinaciones C2 y C3 resultaron tener mayor efecto con relación a la capacidad antioxidante en ecotipos Roja y Chañu.

Estos hallazgos muestran que la iluminación con luces LED es una estrategia para mejorar el potencial nutricional en alimentos con alto valor alimenticio como los brotes de quinua, debido al incremento en la capacidad antioxidante y el contenido fenólico.

Estos hallazgos exponen que la iluminación con luces LED es una estrategia para mejorar el potencial nutricional en alimentos con alto valor nutricional como los brotes de quinua, debido al incremento en la capacidad antioxidante y el contenido fenólico.