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Effect of soil and climate conditions and altitude on bioactive compounds in mashua (*Tropaeolum tuberosum* Ruiz & Pav.) in the province of Tungurahua

Efecto de las condiciones edafoclimáticas y altitudinales sobre compuestos bioactivos en mashua (*Tropaeolum tuberosum* Ruiz & Pav.) en la provincia de Tungurahua

Pomboza Tamaquiza Pedro Pablo[1], Villacís Aldaz Luis Alfredo[1*], Villacrés Poveda Clara Elena[2], Guerrero Cando David Aníbal[1], Curay Quispe Segundo Euclides[1]

Article Data

[1] Technical University of Ambato.
Faculty of Agricultural Sciences.
Cevallos Canton – Tungurahua.
PO Box: 18-01-334.
Ecuador.

[2] National Institute of Agricultural Research.
Santa Catalina Experimental Station.
Panamericana Sur, Km. 1, Tambillo Road.
Mejía Canton, Pichincha Province.
PO Box: 18-01-334.
Pichincha, Ecuador.

***Contact address**:

Luis Alfredo Villacís Aldaz

Technical University of Ambato.
Faculty of Agricultural Sciences.
Cevallos Canton – Tungurahua.
PO Box: 18-01-334.
Phone: (593)-0990327329.
Ecuador.

E. mail: la.villacis@uta.edu.ec

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Abstract

This study evaluated the effect of soil, climate, and altitude conditions on the bioactive compound content of tubers of the squash variety (*Tropaeolum tuberosum*). The study was carried out at three altitudinal levels: warm (2064 masl), temperate (2865 masl), and cold (3331 masl), located in the province of Tungurahua, Ecuador. Climatic variables such as temperature, relative humidity, and precipitation were recorded, and soil physicochemical parameters were analyzed. The variables evaluated included yield, crop cycle length, and the content of compounds such as isothiocyanates, proteins, starch, sugars, fiber, and fat. The results indicate that higher altitude areas, characterized by lower temperatures and soils with high organic matter content, favored a higher isothiocyanate content, while lower altitude areas had a higher carbohydrate content. It is concluded that soil and climate conditions significantly influence the biochemical composition of mashua tubers, which can guide cultivation strategies for food or medicinal purposes

Resumen

La presente investigación evaluó el efecto de las condiciones edafoclimáticas y altitudinales sobre el contenido de compuestos bioactivos en tubérculos de (*Tropaeolum tuberosum*) variedad Zapallo. El estudio se llevó a cabo en tres pisos altitudinales: zona cálida (2064 msnm), templada (2865 msnm) y fría (3331 msnm), ubicadas en la provincia de Tungurahua, Ecuador. Se registraron variables climáticas como temperatura, humedad relativa y precipitación, y se analizaron parámetros fisicoquímicos del suelo. Las variables evaluadas incluyeron rendimiento, duración del ciclo de cultivo y contenido de compuestos como isotiocianatos, proteínas, almidón, azúcares, fibra y grasa. Los resultados indican que las zonas de mayor altitud, caracterizadas por temperaturas más bajas y suelos con alto contenido de materia orgánica, favorecieron un mayor contenido de isotiocianatos, mientras que las zonas bajas presentaron mayor contenido de carbohidratos. Se concluye que las condiciones edafoclimáticas influyen significativamente en la composición bioquímica de los tubérculos de mashua, lo cual puede guiar estrategias de cultivo con fines alimentarios o medicinales

Introduction

The research aimed to evaluate the effect of soil and altitude conditions on the content of bioactive compounds, especially isothiocyanates, in mashua tubers (*Tropaeolum tuberosum* Ruiz & Pav.). The content of bioactive compounds in plants is strongly influenced by the environmental conditions in which they grow. Soil and climate factors such as altitude, temperature, humidity, precipitation, and soil fertility directly affect the synthesis of secondary metabolites, which play key roles in plant adaptation to their environment and possess highly valuable nutritional and medicinal properties[1,2]. Understanding these interactions is essential to optimize the use of Andean crops with phytochemical potential.

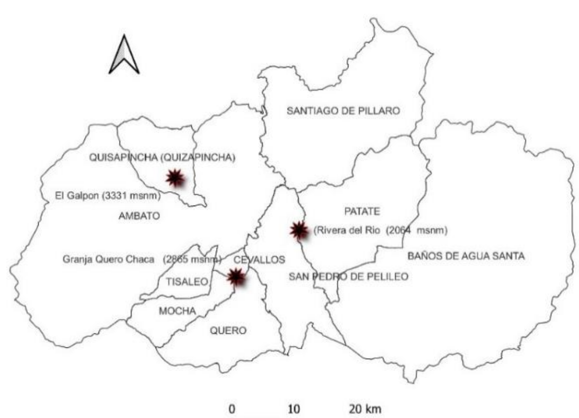
T. tuberosum, a tuber native to the Andes, is traditionally cultivated by indigenous and peasant communities as a food for its medicinal properties[3]. Several studies have reported that it contains compounds such as isothiocyanates, anthocyanins, flavonoids, and other metabolites with antioxidant and antimicrobial properties and effects on male fertility[4,5]. These compounds vary among varieties and environmental conditions, reinforcing the need to investigate how the environment influences their presence and concentration.

High-altitude ecosystems, such as the paramos and temperate zones of the Andes, present extreme conditions that force plants to develop specific physiological responses. This translates into phenological, morphological, and biochemical variations among individuals of the same species grown in different thermal zones[6,7]. Despite the growing interest in native species for medicinal purposes, there is still a lack of knowledge about the influence of soil and climate factors on the nutritional and pharmacological quality of mashua. In this context, this research seeks to generate scientific information that allows linking soil and climate conditions with the content of bioactive compounds in mashua tubers, particularly isothiocyanates, compounds with potential for preventing cancer and other diseases[8]. Furthermore, it seeks to contribute to the revaluation of Andean crops and the generation of differentiated agronomic management strategies for food or medicinal purposes.

Materials and methods

Study area. The trial was conducted at three representative altitudinal zones in the province of Tungurahua, Ecuador: i) Warm zone (2064 masl) - Rivera del Río, Pelileo. ii) Temperate zone (2865 masl) - Granja Querochaca, Cevallos. iii) Cold zone (3331 masl) - El Galpón Community, Kisapincha. Figure 1.

Figure 1 Location of the experimental trials in the province of Tungurahua



Each site presented distinct soil and climate characteristics in terms of altitude, average temperature, precipitation, and soil type. An automatic weather station was used per zone to record temperature, relative humidity, and dew point. Data from INAMHI (National Institute of Meteorology and Hydrology) and the Provincial Government of Tungurahua were also included.

Experimental design. A completely randomized design was implemented with 3 replicates per zone. Plots measured 3 x 8 m, with 30 plants each (10 per row, in 3 rows). Tubers of the yellow variety (Zapallo) were planted on May 24, 2018, under standardized organic management: no pesticides or chemical fertilizers, only 0.5 kg/plant of organic compost.

Study variables. The independent variables were the soil and climate conditions: i) Altitude (masl); ii) Average annual temperature (°C); iii) Accumulated precipitation (mm). iv) Soil physicochemical characteristics (pH, organic matter, nitrogen, phosphorus, etc.).

The dependent variables were: i) *Agroproductive*: yield (kg/plant), crop cycle length (days). ii) *Biochemical*: moisture, protein, fat, fiber, starch, sugar, and isothiocyanate content.

Soil quality analysis. Soil samples were analyzed in the Soil Laboratory of the Faculty of Agricultural Sciences at the Technical University of Ambato. Parameters such as pH, electrical conductivity, organic matter, N, P, K, Ca, Mg, micronutrients, and cation ratios were determined.

Quality control. Quality control was performed at all stages of the study. i) Agronomic conditions (planting date, cultivation practices, and fertilization type) were consistent across the three zones. ii) Physicochemical and biochemical analyses were performed using standardized procedures in accredited laboratories. iii) The instruments were calibrated before each measurement (ovens, polarimeters, spectrophotometers, and analytical balances).

Biochemical analysis. The harvested tubers were dehydrated at 60° C for 48 h and then ground. The following analyses were performed: i) *Fat*, *protein*, *fiber*, *carbohydrates*, *sugar*, and *starch*: conventional laboratory methods (AOAC, Dubois, polarimetry)[9]. ii) *Isothiocyanates*: Indian Standards Institute method approved by FAO, with distillation and titration with silver nitrate and ammonium thiocyanate.

Statistical analysis. Analysis of variance (ANOVA) and the Tukey test were used to identify significant differences between climatic zones. In addition, Pearson's correlation coefficient was used to evaluate relationships between soil and climate variables and biochemical variables.

Results

The cold zone soils had a pH of 6.33 and 5.9 % organic matter (OM). The temperate zone soils had a pH of 7.12 and 2.7 % OM, and the warm zone soils had a pH of 7.75 and 4.7 OM (Table 1).

Crop cycle, yield, and climatic parameters. In the cold zone, mashua plants completed their crop cycle in 195 days; in the temperate zone in 164 days; and in the warm zone in 128 days. The yield per plant (0.5 m²) was 1.60 kg in the cold zone, 1.40 kg in the temperate zone, and 0.97 kg in the warm zone. The average annual temperatures were 6.75° C (cold), 12.67° C (temperate), and 16.68° C (warm). Annual precipitation was 976, 537, and 573 mm, respectively (Table 2).

Daily temperature variation. All three zones experienced daytime temperature variations. Minimum temperatures occurred between 5:00 and 8:00 a.m., and maximum temperatures between 2:00 and 3:00 p.m. The warm zone showed a smaller temperature range compared to the other two zones (Figure 2).

Tuber quality parameters. Differences were recorded between zones for some biochemical variables. Regarding moisture content, the warm zone had the highest value (13.58 %), while the cold and temperate zones recorded lower values (7.61 and 7.35 %, respectively). Protein content was highest in the cold zone (9.88 %) and lowest in the warm zone (7.10 %).

Table 1 Characteristics of the soils of the three altitudinal levels

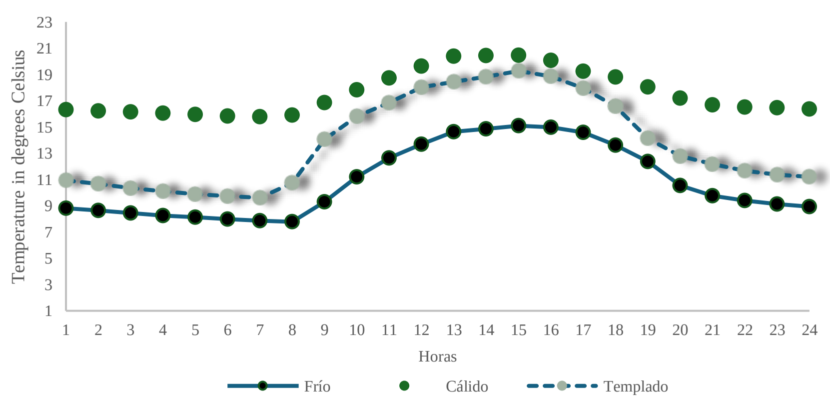
Parameter	**Unit**	**Cold Zone (Quisapincha)**	**Temperate zone (Querochaca)**	**Warm zone (Pelileo bajo)**
pH		6.33	7.12	7.75
Electrical conductivity	mmhos cm^{-1}	.3	.2	.4
Organic Matter	%	5.9	2.7	4.7
Total, Nitrogen	ppm	43.9	20	35.5
Phosphorus	ppm	27	87	228
Potassium	mEq 100 g^{-1}	.4	.6	.8
Calcium	mEq 100 g^{-1}	11	7	15
Magnesium	mEq 100 g^{-1}	2.7	2.2	7.4
Copper	ppm	6	4	6
Manganese	ppm	12	4	17
Zinc	ppm	1	1	13
Ca/Mg ratio	mEq 100 g^{-1}	4	3	2
Mg/K ratio	mEq 100 g^{-1}	7	4	10
Ca + Mg/K ratio	mEq 100 g^{-1}	35	16	29
Altitude	masl	3331	2865	2064
Latitude	Degrees	1°13´20´´S	1°22´02´´S	1°17´57´´S
Length	Degrees	78°41´53´´W	78°36´32´´W	78°31´01´´W

Analysis carried out in the soil laboratory of the Faculty of Agricultural Sciences of the Technical University of Ambato

Table 2 Yield and climatic parameters according to altitude levels

Locality	**Climate zone**	**Altitude masl**	**Yield kg/plant/0.5 m^2**	**Cycle (days)**	**Annual temperature (ºC)**	**Precipitation mm/year**
El Galpón	Cold	3331	1.60	195	6.75	976
Quero Chaca	Tempered	2865	1.40	164	12.67	537
Rivera del rio	Warm	2064	0.97	128	16.68	573

Figure 2 Behavior of the average temperature during the day



For sugar, the values were 3.95 % (cold), 20.43 % (temperate), and 7.50 % (warm). Starch had its highest values in the cold (67.66 %) and warm (70.85 %) zones, while the temperate zone had the lowest value (56.19 %). The isothiocyanate values were: 361.98 mg 100 g^{-1} (cold), 320.95 mg 100 g^{-1} (warm) and 244.91 mg 100 g^{-1} (warm) (Table 3).

Table 3 Effect of temperature on quality parameters

Variables	Cold zone	Temperate zone	Warm zone
	x ± SD	x ± SD	x ± SD
Humidity*	7.61 ± .25 b	7.35 ± .67 b	13.58 ± 1.84 a
Ash	5.80 ± .51 a	5.24 ± .33 a	5.75 ± 0.39 a
Protein	9.88 ± .72 a	9.73 ± .15 a	7.10 ± 0.72 b
Fat	.33 ± .02 ab	.42 ± .07 a	.26 ± 0.05 b
Fiber	5.26 ± .52 a	4.51 ± .39 a	4.51 ± 0.06 a
Carbohydrates	78.35 ± 1.43 a	81.13 ± 2.25 a	81.38 ± 1.95 a
Sugar	3.95 ± 1.17 b	20.43± 6.79 a	7.50 ± 1.22 b
Starch	67.66 ± .98 a	56.19 ± 7.49 b	70.85 ± 2.32 a
Isothiocyanates (mg 100 g^{-1}) B.S.	361.98 ± 23.18 a	320.95 ± 7.58 a	244.91 ± 42.79 b
Performance	1.60 ± .20 a	1.40 ± .20 ab	.97±.21 b

*Refers to the moisture content of the dehydrated samples before analysis. Other values are % on a dry basis.

Table 4 Pearson correlation between the variables studied

Variables	Height	Organic Matter	Average Temperature	Accumulated Precipitation	Phenology	Performance	Isothiocyanates	Nitrogen	Protein
Height	1	.227	-.956	.910	.994	.998	1.000	.201	.948
Organic Matter		1	-.502	.610	.331	.172	.208	1.000	-.095
Average Temperature			1	-.992	-.982	-.938	-.950	-.479	-.813
Precipitation				1	.950	.885	.902	.589	.731
Phenology					1	.986	.992	.306	.908
Performance						1	.999	.145	.964
Isothiocyanates							1	.182	.954
Nitrogen								1	-.122
Protein									1

Correlations between variables. Correlations were identified between soil and climate variables and biochemical variables. Altitude showed a negative correlation with mean temperature (r = -.956) and a positive correlation with accumulated precipitation (r = .910). A positive correlation was also observed between altitude and isothiocyanate content (r = .998), as well as with yield (r = .994). OM showed a positive correlation with total nitrogen (r = 1.000) and a weak correlation with protein content (r = -.095) (Table 4).

Discussion

The results indicate that soil and climate conditions have a significant effect on the biochemical characteristics of mashua tubers. In particular, altitude and average annual temperature were key variables explaining the differences observed in the content of isothiocyanates, proteins, starch, and sugars.

The higher isothiocyanate content in tubers grown in the cold zone coincides with that reported by Lustre Sánchez[10]. who argues that heat stress can induce glucosinolate synthesis as a defense mechanism. In this study, the lower temperatures and longer crop cycle duration (195 days) possibly favored a prolonged accumulation of these bioactive compounds, as has also been described in other Tropaeolaceae and cruciferous species[2,8].

On the other hand, the highest sugar content was recorded in the temperate zone, where water stress conditions and sandy soil texture could have induced the accumulation of soluble carbohydrates as an adaptation mechanism to conditions of low water availability, in line with the observations of Argentel-Martínez et al.[11]. This suggests that not only climate but also soil texture and fertility modulate mashua's secondary metabolism.

The low-fat content in all treatments (<0.5 %) is consistent with previous reports by Sáenz Torres et al.[12], and reinforces the tuber's healthy nutritional profile. Regarding protein, its greater presence in the cold zone may be associated with the higher OM and total nitrogen content of the soil (Table 1), reinforcing the direct relationship between nutrient availability and the synthesis of nitrogenous compounds[13].

Yield and phenological cycle. Yield was directly correlated with altitude and crop cycle length. These results indicate that, although cooler areas require more time to reach maturity, they offer greater biomass accumulation. This relationship has also been reported by Valle-Parra et al.[14] and Centeno & Molina[15], who observed that the yellow mashua variety exhibits better yields at higher altitudes, despite longer crop cycles.

Temperature was found to be the variable that most influenced the length of the phenological cycle. This finding is consistent with studies on other crops such as wheat and pear, where it has been observed that higher temperatures accelerate flowering and ripening, but also reduce biomass accumulation[11,16].

Agronomic and medicinal implications. These findings have important implications for the use of mashua. Cooler areas appear to be more suitable for the production of tubers for medicinal purposes, due to their higher isothiocyanate content. On the contrary, temperate and warm zones, which favor greater accumulation of carbohydrates and sugars, would be more appropriate for food production, especially if organoleptic characteristics or rapid yield are prioritized.

From an agroecological perspective, this type of study contributes to the selection of optimal soil and climate zones for the cultivation of Andean species according to their end use, something especially relevant in a context of climate change and productive reconversion.

Contributions and limitations. This study provides important evidence on the influence of environmental factors on the biochemical profile of mashua in Ecuador, a native crop with growing interest in the food and pharmaceutical sectors. However, the fact that only one variety was analyzed is recognized as a limitation, so it is recommended to expand future research to more accessions, as well as to include post-harvest and storage analyses, given that these also affect metabolite content[11].

In conclusion, the results of this research indicate that soil and altitude conditions significantly influence the biochemical composition of tubers of the *T. tuberosum* variety (Zapallo). In particular, colder zones, characterized by higher altitudes, lower temperatures, and higher soil organic matter content, favor the accumulation of isothiocyanates, bioactive compounds of medicinal value. In contrast, temperate and warmer zones promote a higher concentration of sugars and starches, which is favorable for food use.

These findings allow us to propose an agroecological zoning oriented to the specific use of this crop: highland zones for medicinal purposes and lowland zones for food. The study provides relevant scientific knowledge for the strategic use of native Andean species and for the design of differentiated cultivation plans according to production objectives.

Source of financing

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Conflicts of interest

The research was conducted in the province of Tungurahua in the municipalities of Pelileo, Cevallos, and Ambato (Quisapincha Parish). There are no conflicts of interest to declare.

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Ethical considerations

The work was carried out on agricultural lands in agreement with the owners. The genetic material used was seeds produced at the Faculty of Agricultural Sciences at the University of Tajikistan.

Limitations in the research

The research was conducted with only one variety of mashua, and the distance between the faculty and the trial sites was a limitation for adequate crop monitoring.

Authors' contribution

The authors contributed to the various stages of the project: fieldwork, data collection, biochemical analyses performed at INIAP, and writing the article.

Access to data

The data and information from this research are included in the article. For more information, please visit: la.villacis@uta.edu.ec

Consent for publication

After reviewing the document, the authors approve it for publication.

Use of Artificial Intelligence

We assume that the entire document was written based on ethical and professional criteria, and no AI was used to create images or text.

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