Description of saponins in quinua (*Chenopodium quinoa* willd) with relation to the soil and the climate: a review

Descripción de las saponinas en quinua (*Chenopodium quinoa* willd) en relación con el suelo y el clima: Una revisión

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Abstract

Increasingly, the production of quinoa *(Chenopodium quinoa* Willd*)* in different regions of the world becomes more important, due to the fact that it has been sought to position the crop as an alternative to food security. However, this plant has metabolites such as tannins and saponins, which are chemical substances that serve as protective barriers to biotic and abiotic factors. In the case of saponins, 31 chemical structures are recognized, present in leaves, stems, panicles, husk, and seeds of different species and genotypes. In this regard, this review seeks to describe the general characteristics of the saponins present in quinoa and its relations with soil and climate. Finding that the edaphoclimatics characteristic of each place as well as the genetic characteristics of each variety are determinants in the content of saponin compounds stimulated mainly by water and saline stress.

Keywords: edaphic; climate; saponins; salinity.

Resumen

Cada vez, toma mayor importancia la producción de la quinua *(Chenopodium quinoa* Willd*)* en diferentes regiones del mundo, debido a que se ha buscado posicionar el cultivo como una alternativa de seguridad alimentaria. Sin embargo, esta planta presenta metabolitos como taninos y saponinas que son sustancias químicas que sirven de barreras de protección a factores bióticos y abióticos. En el caso de las saponinas, se reconocen 31 estructuras químicas, presentes en hojas, tallos, panojas, cascarilla y semillas de diferentes especies y genotipos. Al respecto, esta revisión busca describir características generales de las saponinas presentes en la quinua y su relación con el suelo y el clima. Encontrando que las edafoclimáticas propias de cada lugar, así como las características genéticas de cada variedad son determinantes en el contenido de compuestos saponínicos, estimulados principalmente por estrés de tipo hídrico y salino.

Palabras clave: edáficas; clima; saponinas; salinidad.

Introductión

Quinoa *(Chenopodium quinoa Willd)*, also known as parca *(Quechua)*, supra, jopa, juira and vocali (Aymara) (Cáceres-Ríos, 2016), is a species belonging to the Amaranthaceae family, native to the southern region of America, mainly from countries such as Peru, Ecuador, Chile, Bolivia and Colombia, characterized by being the economic, social and food base of indigenous peoples since 2000 BC, being a symbol of abundance, religiosity and fertility (Andrews, 2017), thus Bolivia has been recognized as the world's leading producer and exporter of real organic quinoa with 46 % (Lozano, Ticona, Carrasco, Floresa and Almanzaa, 2012); taking relevance during the last years in North America, Europe and Africa (VilSCCundo and Hernández-Ledesma, 2017).

Therefore, quinoa has become one of the main agri-food strategies in different regions of the world, given its protein content of 12-21 % (Comai *et al.*, 2007), 2-9.5 % fat (García -Parra, García-Molanoa and Carvajal-R, 2018) and fiber of 8.8-14.1 % (Navruz-Varli, 2016), as well as the presence of all the essential amino acids and the absence of gluten (Nowak, Du, and Charrondie, 2016), besides expressing good results of adaptability to extreme climate and soil conditions, which has allowed to colonize unproductive zones (Carrasco, 2016), since as a result of the natural crosses that were generated with *C. carnosulum, C. petiolare* and *C. pallidicaule,* conferred the ability to withstand a greater proportion of salinity stress and frost resistance (Mujica and Jabobsen, 2006).

On the other hand, this species is classified into five large agroecological groups, according to edaphic and climatic requirements, corresponding to the quinoas of the sea level, the salt flats, the jungles, the inter-Andean and highland valleys (Bazile, Bertero and Nieto, 2014), an aspect that has strengthened the expression of its genetic potential. However, the agroindustrial development of quinoa has been disadvantaged, because the seeds synthesize bioactive compounds in response to adaptability (Cruces, 2016), which has generated that the consumption causes toxicity to the organism, due to the effect of irritation in the digestive tract and intestinal mucous membranes, inhibiting the absorption of nutrients and producing cell lysis (Costa, Yendo, Fleck, Gosmann and Fett-neto, 2011).

In addition, quinoa has been classified into sweet and bitter varieties, according to the content of saponins (Vega-Gálvez *et al*., 2010), a secondary metabolite that is synthesized from the biosynthesis of acetic acid that is transformed into mevalonic acid, after passing to farnesyl pyrophosphate and forming a molecule of squalene that is capable of becoming a triterpene sapogenin or steroidal sapogenin (Szakiel, Paczkowsky and Henry, 2011), this is how the structure of saprogenic compounds is made up of a molecule of bound aglycone by means of a glycosidic bond to a sugar (Ahumada, Ortega, Chito, and Benítez, 2016), generating about thirty different saponins that are constructed through the combination of sugars and aglycones present in stems, leaves, seeds, panicles and flowers, and influenced by soil and climate conditions, which are determinants of the amount of these compounds and that allow adaptability to biotic factors and biotic (Apaza, Smeltekop, Flores, Almanza, and Salcedo, 2016).

In addition, it has been established that the crop has a genetic diversity and ample capacity to adapt to different climates and soils with different texture and pH between 4,5-9, as well as its high resistance to drought, frost, and salinity, (Carrillo, Vilsccundo and Carpio, 2015; Veloza, Romero and Gómez, 2016). For this reason, it is necessary to know theoretically the general characteristics of the saponins present in quinoa and its relationship with soil and climate.

Generalities of saponins in quinoa

Saponins are a secondary metabolite, abundant in the plants of the genus Chenopodiaceaea, being one of the main anti-nutrients that have the plants of C. quinoa and that give the bitter characteristic to their grains, constituted by a large group of glycosides present in organs such as leaves, stems, and panicles, being produced in the cytosol, from the synthesis of the squat and structured with lipophilic and hydrophilic sections (Francis, Kerem, Makkar and Becker, 2002; 2017). This glucoside is characterized by being of high molecular weight, being structurally shaped by an aglycone (terpenoid or steroidal) linked to carbohydrates (sugars) through glucosidic bonds (Ahumada *et al*., 2016), which form monoglycosidic, glycosidic or triglycosidic saponins according to the number of substitutions (Guzmán, Cruz, Alvarado and Mollinedo, 2013).

According to the above, the synthesis of saponins occurs with the mixture of structural carbohydrates mainly pentoses, hexoses or uronic acids (Moses, Papadopoulou and Osbourn, 2014) and the aglycones can be oleanolic acid, hederagenin, acid 3β, 23, 30-trihydroxy Olean-12-ene-28-oico, gipsogenin, espergulagenic acid, 3β-hydroxy-27-oxoolean-12-ene-28-oico acid, organic acid and phytolacagenic acid (Cuadrado, Ayet, Burbano, Muzquiz and Caviares, 1995) giving as origin to about 31 saponins, thus being able to identify specialized types of aglycones, as described by Mizui, Kasai, Ohtani and Tanaka, (1990), who find that the hederagenin is the aglycone that predominates in the seeds, but that however, this may change depending on the variety, climate and soil.

Among the biological properties of saponins is the antibacterial capacity, as well as its use for treatments of cholesterol and cancer (Apaza *et al*., 2016); On the other hand, research has been carried out aimed at plant health, where the ability to control pests and diseases mainly of fungal origin has been recognized, such as Botrytis sinerea, Pomácea canaliculata Lamarck, Aspergillus and Fusarium (Guzmán et al., 2015).

Therefore, saponins are characterized as substances that quinoa plants produce at higher or lower concentrations, regardless of whether they are found in sweet or bitter varieties according to Gómez-Caravaca, Lafelice, Verardo, Marconi, and Caboni. (2014), sweet varieties have less than 0.11 %, while bitter varieties have higher values, being a changing factor and dependent on the variety and edaphoclimatic conditions.

Saponin Relationship - Climate

Climate is an indispensable factor in the development of quinoa plants, given that their functioning and ecophysiological response varies depending on the production area, while according to Bazile *et al*., (2014) the climate and soil conditions are variants according to the agroecological groups in which the different varieties are characterized. It is in this way that the availability of water becomes indispensable in the dissolution of nutrients present in the soil that are the bases of growth and development of all plant species; Likewise, solar radiation acts on the leaf blades, being captured in the form of light energy and transformed into solar energy, and temperature is an influential variable in chemical, enzymatic and metabolic activities and reactions (García-Parra, García-Molano, Melo and Deaquiz-Oyola, 2017), where we find a compound of secondary metabolism such as phytic acid and saponins, which are synthesized when the plant is exposed to biotic or abiotic stress.

However, the strong climatic variations have caused the plants to develop strategies in response to the effects of stress, which are mainly due to the water deficit effect or as adaptive responses to an abrupt effect of the conditions where it has been implemented (Delatorre- Herrera, González and Martínez, 2015), which allowed observing according to Szakiel, *et al*.,. (2011), the synthesis of secondary metabolites such as saponin when the weather conditions are not adequate for the type of variety or ecotype.

As reported by Mori (2015), quinoa is a plant that expresses saponin contents according to the availability of water, because the point of permanent withering or waterlogging stimulate the metabolic expression of this compound, since the presence and Water availability in the soil facilitates the absorption and active and passive transport of nutrients, while the increase in osmotic pressure reduces the flow of molecules and minerals into the plant, stimulating stress and decreasing normal development of physiological activities (Deaquiz-Oyala, 2014).

Another factor influencing the synthesis of saponins is the temperature since it directly affects the accumulation of bioactive compounds in the different organs of the plant, thus tolerating temperature ranges between 0 and 30 °C (Gómez and Aguilar, 2016), which is determinant according to the thermal condition in the variation of the synthesis of glycosides and especially of saponins (Schwarzbach, Scheiner and Knorr, 2005).

Also, the photoperiod is recognized as one of the main sources of energy from solar radiation, captured as light energy and transformed into chemical energy through photosynthesis, being determined in processes that manage to generate changes in the behavior of plants, because the wave of light capture must be between 400 and 700 nm, which allows correlating with the presence of metabolites in certain productive stages such as flowering for Chenopodiaceae (Janick and Whipkey, 2002). On the other hand, the relationship between precipitation, temperature and photoperiod, shows its effect on the metabolic expression of plants and mainly against the synthesis of substances that are synthesized by stress effects (see Table 1).

Table1.

Effect of temperature, precipitation, and photoperiod in the presence of saponins

Country	Variety	Climate			Saponin content	Author
		T (°C)	Precipitatión (mm)	photoperiod (h/luz)		
Chile	Regalona	20 ºC	----	16	0,52 mg.L-1	(Delatorre-Herrera *et al.*,2015)
		30 ºC	----	16	0,62 mg.L-1	
Perú	INIA Salcedo	25 ºC	1,15	----	0,168 %	(Mori, 2015)
			0,55	----	0,089 %	
Perú	Blanca de Junin	13 ºC	65,3	----	0,0150 %	(Canales, 2016)
		13 ºC	54,5	----	0,0210 %	

Source: the authors.

The previous table correlates the climatic conditions established for different quinoa varieties and their effect on the presence of saponin, for the case of the regional variety, the effect of temperature on the saponin concentration is remarkable; agreed with the exposed by Gómez-Caravaca *et al*., (2014), thermal extremes influence the increase of saponin present in the different organs of quinoa plants. Likewise, we can observe the effect of precipitation levels in the studies of Peru, where the increase and reduction of precipitation generate effects in the concentration of saponin in the quinoa seeds, probably being induced by the effect of stress, drought or flooding and the conditions of the subsystems that allow demonstrating the response of the plant to edaphoclimatic conditions (Motta-Delgado and Ocaño-Martínez, 2018).

Saponin – Soil

Soil is the most important resource for plants at the time of nutrition since it contains a large part of the minerals necessary to develop the physiological and metabolic activities, which together with the microorganisms act in correlation and in many cases in coevolution to satisfy the needs one from the other. However, Chenopodiaceas is not recognized so far symbiotic populations at the rhizospheric level that contribute to the nutrition of the plant and that favor the development of these under adverse edaphoclimatic conditions (Carvajal, 2011). However, the physical, chemical and microbiological characteristics of the soil generate effects in the synthesis of substances such as primary and secondary metabolites that contribute to the normal development of the plant, creating protection barriers against biotic and abiotic agents, since the intake of elements as nitrogen (N), phosphorus (P) and potassium (K) are absorbed in greater quantities and are part of the structure of some compounds of the group of glycosides within which is the saponin (Rosero, Maraunek, Bienova and Lukessova, 2013).

Some studies have focused on the effect of soil salinity and irrigation on the content of saponin stimulated through the stress they cause when they are deficient in water or in waterlogging, however, it is stated that when plants Quinoa are exposed to these factors, the presence of this group of secondary metabolites is reduced (Troisi *et al*., 2014), which could influence the agro-industrial potential of the seeds. However Janick and Whipkey (2002), they determined that, on the contrary, quinoa increases its content of saponin in the seed when it is under stress due to water deficit, soil conditions being an important factor in the concentration of saponin according to the variety and the environment (see Table 2).

Table 2.

Saponin content depending on the variety and soil and climate conditions

Variety	Place	Saponin (%)	m.s.n.m	Soil	Temperature (°C)	Author
PEQPC-461grano negro	Perú	0,91	243	50-69-00	16-24	(Mendoza, 2013)
Quinua Zolapozada	----	1,1	2800	Clay soils, without fertilization	25	(Zerraga, 2010)
Ingapirca Blanca opaca	Ecuador	0,07	2600	80-40-30	14	(Nieto, Vimos, Mon- teros, Caicedo y Rivera, 1992)
INIAP Pata de venado	----	0,27	3058	----	14	(Maggi, 2016)
Real de Bolivia (Amarga)	Bolivia	2,6	27	Soil	22	(Pappier, Fernández, Larumbe y Vaamon- da, 2008)
Piabiru Amarga	Brazil	3,3	8	Soil	14	(Nickel, Spanier, Botelho, Gularte y Helbing, 2016)
Regalona Chile (Sweet)	Chile	0,002	10	----	25	(Kuljanabhagavad, Thongphasuk, Cha- mulitrat y Wink, 2008)
Blanca de Nariño	Colombia	0,5	2800	Clay loam	12	(Guzmán, 2017)
Regalona	Chile (costa)	2,2	20	Sandy soils (saline)	22	(Orsini *et al.*,2011)

Source: the authors.

According to the previous Table, it is evident that the PEQPC-461 variety of Peru has a high percentage of saponin, which is probably due to the temperature at which it was developed, taking into account that at that level of the sea the climates they are mostly dry and influenced by underground and superficial marine water currents, as well as Zolaposada quinoa that developed in a warm climate without fertilization and clay soils. In addition, it can be shown that water stress is an important factor in the behavior of the plant because being scarce, there is a slight increase in the production of secondary metabolic substances that are expressed as a result of the effects (Santacoloma and Granados, 2012), which also happens in the Real variety of Bolivia, where the saponin contents were 2.6 % with temperatures of 22 ºC during the trial (Pappier *et al*., 2008).

On the other hand, the Piabiru variety of Brazil is a genotype cultivated in Brazilian soil and climatic conditions, recognized by the synthesis of high saponin contents, given that this geographical area is not characterized as technically suitable for the production of quinoa (Nickel *et al*., 2016), to which the increase in this metabolite can be attributed, together with the excessive presence of salts at ground level. This in response to the facultative halophytic capacity expressed by plants (De Santis *et al*., 2016), while the soil and environmental moisture content are decisive in the intake, assimilation and moderate elimination of salt particles, which according to Ruiz- Carrasco *et al*., (2011) this mechanism stimulates the synthesis of saponins at leaf level by the proline effect. In addition, for the case of varieties grown in the coastal zone of Chile, the permanent increase in soil osmotic pressure is given by the natural irrigation of marine waters that have high salt contents that influence stress and the subsequent increase in saponin compounds (Orsini *et al*., 2011).

Conclusions

The concentration of saponins in the quinoa seed is influenced by the agroclimatic characteristics of the production area, mainly due to changes in temperature, which affect the accumulation of bioactive in the different organs of the plant, the availability of water and the photoperiod, since they have an effect on the metabolic activity of plants and the synthesis of these substances that occurs due to stress effects.

On the other hand, soils with salinity contents affect the agro-industrial potential of quinoa seeds, since they stimulate the concentration of saponin compounds.

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