Environmental and Sustainability Indicators 8 (2020) 100063

Contents lists available at ScienceDirect

Environmental and Sustainability Indicators

journal homepage: www.journals.elsevier.com/environmental-and-sustainability-indicators/

Unfrozen state by the supercooling of chuño for traditional agriculture in altiplano andes

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ARTICLE INFO

Keywords:
Climate change
Andes
Traditional food
Supercooling
Chuño

ABSTRACT

The freezing point and supercooling process are discussed for their impact on the traditional Andean freeze-dried potatoes called chuño. The freezing point depends on potato species, but typically it is slightly below zero to −3 °C; supercooling always occurs before the potatoes freeze, and the lowest supercooling point (LSP) can reach −4.3 °C. Recently many of the potato fields near Lake Titicaca are not cold enough to freeze tubers for chuño, and the loss of this food source will be critical in the future.

Introduction

Chuño, the traditional freeze-dried processed potatoes, are made only in the higher elevations of the central Andes, also known as the Altiplano. The chuño process requires temperatures cold enough to freeze the tubers during the night and warm enough to thaw them out during the day. Historically, only the climate of the Altiplano creates these favorable conditions. The history of the chuño stretches more than 2000 years; earthenware containing white chuño was found in Peru's coastal regions dating from the Moche era (100–600 CE). After the Incan era, many Spanish records mention chuño; in particular, Cobo (1956) (original from 1653) described in great detail the appearance and spices of the *Ruki* (*Solanum juzepczukii* and *S. curtilobum*), bitter potatoes used for chuño. The *Ruki* potato is one of the most cold-resistant potatoes in the Andes. They can withstand environments down to −4 °C (Gade, 2016), and they are also disease resistant. However, *Ruki* contain a higher content of glycoalkaloids, and they must undergo the chuño process to be edible. The chuño process produces not only a well-preserved food suitable for long storage, or emergency food, it also removes the poisonous glycoalkaloids, making the potatoes edible. This product is ideal for the Quechua and Aymara people. The chuño process requires: 1) The freeze-thaw process, applied to washed potatoes spread on the ground for about one week. The freeze-thaw cycle needs at least three to four nights, depending on the size of the potatoes and the nighttime temperature. 2) Dehydration, in which the liquid-filled, soft potatoes are stepped on, causing the skin to split and peel away. Most of the water content of the potatoes is removed at this point. Then the potatoes are spread on the ground for another one to two weeks. At this stage, the product is called "black chuño" (chuño negro). Chuño comes in two kinds (black and white). White chuño (also called Tunta, Moraya, chuño blanco) is more valuable and requires three to four weeks of soaking in a water process before starting the freeze-drying process described above. Storing the potatoes in running water leaches out the glycoalkaloids. So white chuño production is associated with water availability. Freeze-thaw cycles are very severe in Altiplano and, in the past, occurred almost every day at an elevation of 4400 m or above. Permafrost (ground frozen consistently for at least two consecutive years) typically starts to occur at 5200 m, on south-facing slopes and at 6000 m on north-facing slopes. These freeze-thaw cycles are influenced by the distribution of the permafrost-related regional climate cycles such as El Niño-Southern Oscillation (ENSO) (Yoshikawa et al., 2020). In the Altiplano, El Niño tends to produce dry and warm conditions, while La Niña episodes are associated with cold and wet conditions (Veettil and Kamp, 2017). Chuño is typically produced slightly below the permafrost lower boundary, between 3800 and 4600 m a.s.l. today. White chuño, because it requires water (preferably running water) for soaking, is not produced in the higher elevations, where running water is less available. This paper examines the freezing temperature of the potatoes and considers the implications for this traditional food source in light of future climatic change.

Methods

Thermistor sensors were located at the middle of the potatoes (potato diameter 7–8 cm) for measuring internal potato temperature. Black potatoes (*Solanum chaucha* Juz. & Buk.) and Canchan potatoes (*Solanum*

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https://doi.org/10.1016/j.indic.2020.100063
Received 13 July 2020; Received in revised form 28 August 2020; Accepted 30 August 2020
Available online 9 September 2020

Fig. 1. Black potatoes (*Solanum chaucha* Juz. & Buk.) and Canchan potatoes (*Solanum tuberosum*) at a chuño field (15°42′S; 71°35.5′W; 4400 m a.s.l.).

tuberosum) were used with sensors at a chuño field (15°42′S; 71°35.5′W; 4400 m a.s.l.) near Chivay town (15°38′S; 71°36′W; 3640 m a.s.l.) in June 2019 (Fig. 1). This site is located on a north-facing slope with a small stream which is used by Quechua people to make chuño during winter months. Another experiment was carried out near Fairbanks, Alaska, during the spring of 2020 when the temperature and humidity conditions were identical to those of Altiplano. For the Fairbanks test, Yukon Gold potatoes (*Solanum tuberosum*) were used and exposed to air temperatures of about +30 to −10°C daily amplitude. Dataloggers were used at both sites (Onset, model U23) with 1-min collection intervals. The accuracy of the temperature observations is ±0.1 °C.

For 2010–2012, the lowest daily temperature data was obtained from the Ministry of Environment Peru, SENEMHI. Five stations data were selected (https://senamhi.gob.pe/?&p=descarga-datos-hidrometeorologicos) based on the variety of the conditions for Altiplano in Huancane (15°12′S; 69°46′W; 3830 m a.s.l.), Chivay (15°38′S; 71°36′W; 3640 m a.s.l.), Taquile Island (15°46′S; 69°41.5′W; 3820 m a.s.l.), Ayachuyo (15°41′S; 70°25.5′W; 3920 m a.s.l.), and Puno (15°50′S; 70°01′W; 3822 m a.s.l.).

Results

Supercooling is the process of lowering the temperature of water (in a liquid state) below the freezing point without ice formation (solid state). Supercooling is not only known in stratus or cumulus clouds, but also some animals utilize it to survive colder temperatures. We observed that the

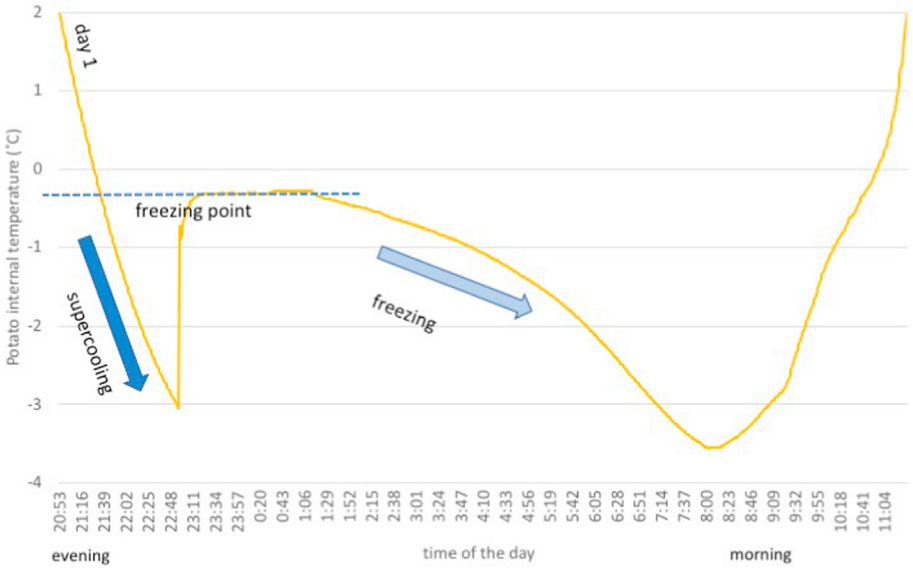

Fig. 2. Time series of the Yukon Gold potato internal temperature. The supercooling temperature reached −3 °C in this figure before freezing. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

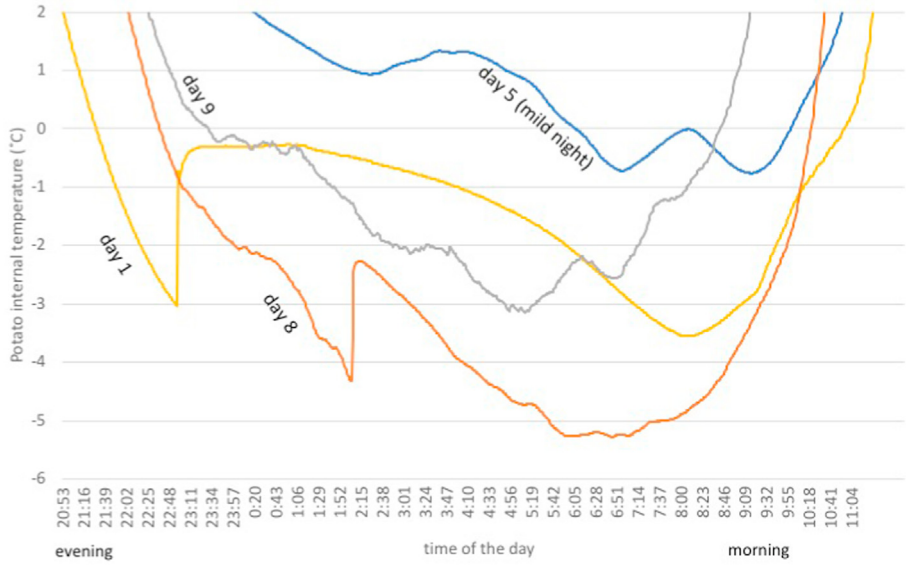

Fig. 3. Time series of the Yukon Gold potato internal temperature, Potatoes underwent freeze-thaw almost every night except on warmer evenings (Day 5 and Day 9). The supercooling temperature reached −4.3 °C on Day 8 and the freezing point was −2.3 °C. During the night of Day 9, the potato never froze even though the internal temperature reached below −3 °C. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

supercooling process took place in the potatoes during each interval of freezing temperatures (Fig. 2). At the beginning, the potatoes never froze when temperatures fell below the freezing point. Then, later, the supercooling state was stopped suddenly, and the temperature jumped up to the freezing point immediately. The difference between the lowest supercooling point (LSP) and the freezing point was 2.8 °C on the first night of the experiment. The trigger to stop supercooling is unknown; however, the LSP is typically 1–3° colder than the freezing point (Fig. 3). During the first few days, the freezing point ranged slightly below zero, −0.17 to −0.2 °C for the Yukon Gold, −0.7 °C for the Black potato, and −1 °C for Canchan potato. The freezing points dropped 1–2 °C after three to four days, most likely due to less water content and precipitated diluted materials. The LSP also dropped, following the drop in the freezing points.

Since 2001, minimum daily temperature rarely reaches below −5 °C at the town of Chivay (Fig. 4). In response the majority of the people have moved to higher elevation for making chuño in last 15 years. Lower air temperatures at Chivay and near Lake Titicaca sites indicated critical conditions for chuño production (Fig. 4). Conditions at Chivay and Puno seem marginal. Huancane and Ayachuyo conditions were still cold enough to support production. Taquile Island, located in the middle of Lake Titicaca, was quite warm and conditions were impossible for making chuño.

Discussion

In our assessment of the freezing process, almost every night supercooling occurs in the potatoes. The LSP typically drops down to 1–3 °C colder than the freezing point. Different species of potatoes have different

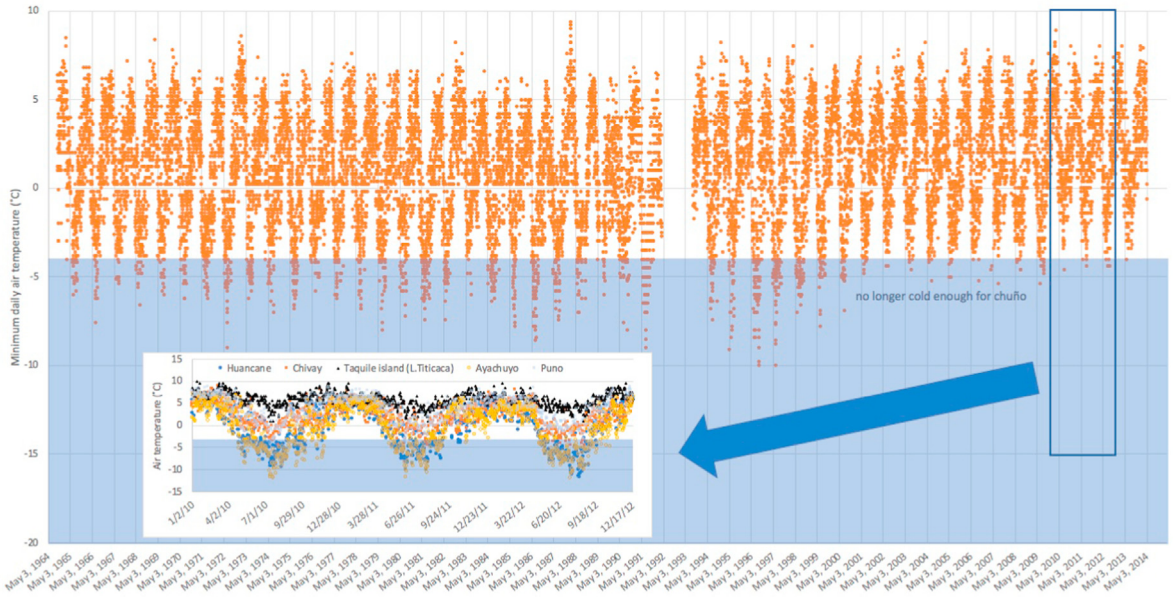

Fig. 4. Minimum daily air temperature was plotted in Chivay (1963–2014) and inserted plot between 2010 and 2012 at Huancane, Chivay, Taquile Island in Lake Titicaca, Ayachuyo, and Puno. The blue shaded area indicates the maximum freezing temperature (−3 °C) of potatoes adequate for the necessary supercooling conditions. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

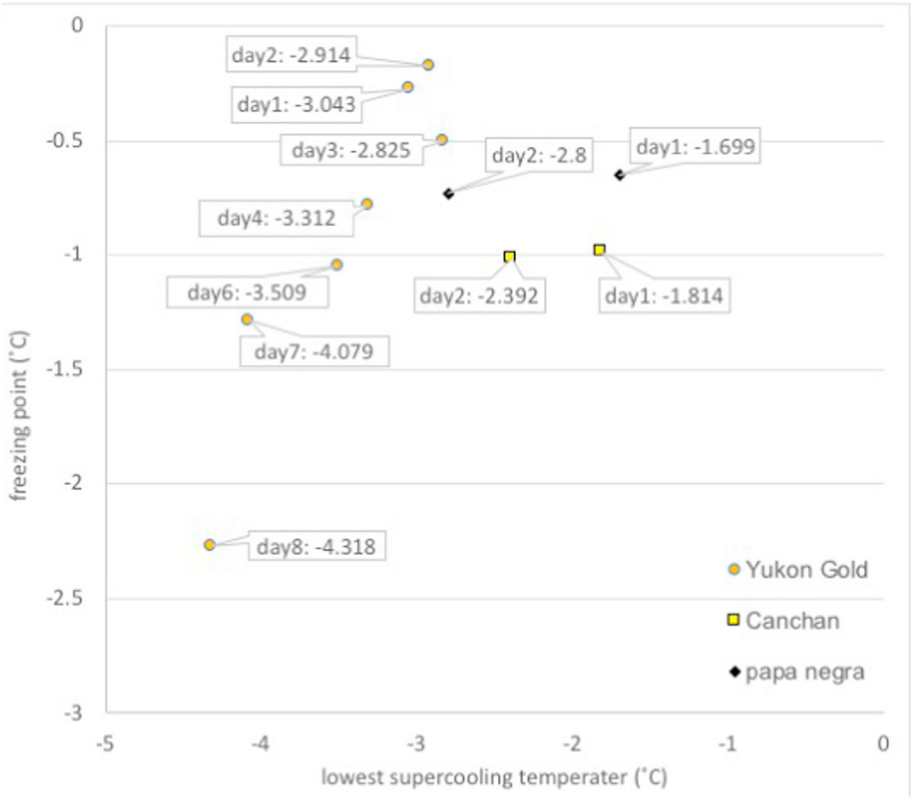

Fig. 5. The relationship between freezing points and the Lowest Supercooling Point (LSP) of three different potatoes. The freeze thaw cycles (day) and LSP temperature are labeled next to each plot.

freezing points. As more repetitions of the freeze-thaw cycle take place, the freezing point and LSP drop as well. The LSP can be much colder (−4 °C or colder), for frost resistant hybrid potatoes. We found that the potatoes were never frozen on a night with only a slight frost (below 0 to −3 °C). The main reason for the unfrozen state was the remaining supercooling; even the potatoes' temperatures fell below the freezing point. The relationship between freezing points and LSP is plotted in Fig. 5. Note that the freezing point and LSP both dropped after days of freeze thaw cycles. This causes water to evaporate from the thawed potatoes and precipitated diluted materials during the daytime. It seems supercooling occurred not only in pure water, but also the higher content of the diluted material lowers the LSP. The mechanism by which this occurs is not known and is open for future study.

Lower air temperature variations show that several sites, such as near Lake Titicaca and/or places where the elevation is below 3600 m, are very close to LSP, which means the conditions are no longer good for making chuño. However, air temperature data alone is not enough to indicate that chuño production will be viable. The ground surface is usually 1–3 °C cooler than the air temperature at night due to thermal radiation cooling. For future consideration of potential for production of traditional chuño products, we should consider: 1) the size/spices of the potatoes used; 2) avoiding nearby big waterbodies; 3) a flat area where better integration of cold air can take place, instead of the mixing air more common on slopes; 4) using lower thermal conductive materials between the ground and the potatoes (such as dried grasses). Once the ground surface is cooling significantly at night, more heat is conducted from the ground to the surface.

Conclusion

This paper discussed the freezing point and supercooling process of the Andean freeze-dried potato called chuño. Many of the chuño fields near Lake Titicaca and Colca Valley areas have faced marginal to complete freezing of the tubers in last 15 years. The freezing point of the potato tubers is not 0 °C; with the involvement of the supercooling state, a temperature of at least −3 °C or colder is necessary to consider successful production of chuño.

Finally, making good chuño in the locations where it has historically been produced will be problematic as the climate continues to warm. Continuing this long tradition of food production will have to be closely monitored to keep track of the temperatures.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

Our sincere thanks and gratitude to Water and Environmental Research Center UAF staff members and Ms. Sandra Boatwright, Isabel Ramos, Eduarda Hilaria Choquehuayta Hilachoque, Rossibel Dileydi Churata Añasco and anonymous reviewers who provided insightful comments and suggestions that improved this manuscript.

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