Article

Accumulation of cold hours for cranberry production in Nayarit, Mexico

Arturo Álvarez-Bravo[1]
Rubén Bugarín-Montoya[2§]
Mairim Elizabeth Arellano-Figueroa[3]

[1]Experimental Field Santiago Ixcuintla-INIFAP. Nayarit, Mexico. CP. 63300. (alvarez.arturo@inifap.gob.mx). [2]Autonomous University of Nayarit-Academic Unit of Agriculture. Amado Nervo s/n, Col. Los Fresnos, City of Tepic Culture, Nayarit, Mexico. CP. 63155. [3]Independent researcher. (maieli51@gmail.com).

[§]Corresponding author: drbugarin@hotmail.com.

Abstract

The climate is a determining factor of the yield and quality in agricultural production systems. The objective of this work was to quantify the cumulative cold hours in Nayarit and to use this information as an agroclimatic indicator in the regionalization to produce cranberry (*Vaccinium corymbosum* L.). The research used data from the network of agrometeorological stations in Nayarit, which consists of 38 automated stations that collected fifteen-minute data of 11 variables. With minimum temperature records, cold hours were calculated, which were organized by month and accumulation per year. Using a geographic information system, the distribution of annual cold hours (HFA) was cartographically represented, with interpolation and organization of the results in four phases (<299, 300-399, 400-499 and 500-699). For each HFA class, the area was quantified in each of the 20 municipalities. Finally, the precision of the interpolation model against a database outside the main data set was evaluated. The results show that only in 27.4% of the state surface accumulate more than 300 HFA which is the minimum requirement for cranberry. The thermal conditions for cranberry are mainly located in the center and south of the state, highlighting the municipalities of Compostela, Xalisco, Tepic, Santa María del Oro, Jala, La Yesca and Ixtlan del Río that represent 81.6% of the apt surface. The results are a precedent for the accumulation of cold hours in Nayarit and serve as a planning tool for decision makers, technicians and producers interested in the cultivation of cranberry.

Keywords: agroclimatology, cold hours, temperature.

Reception date: January 2019
Acceptance date: April 2019

Introduction

In recent decades, the state of Nayarit has undergone a process of productive reconversion, from basic crops to fruit trees and greenhouse vegetables (SIAP, 2017). In this transition process, the adoption of new crops and production technologies has been explored, particularly that of berries under protected agricultural conditions. The latter offers a new conversion alternative with high profitability in a small area (SIAP, 2017). Worldwide, the production of berries or 'frutillas' in Spanish, as is the case of strawberry, blueberry, blackberry or raspberry, has gained economic, political, social and is in full growth and development (Cruz, 2018).

In Mexico, as a response to the growing demand for strawberries in the world, diversification projects have been developed in Michoacán, Baja California, Nayarit and Puebla, among others, which have optimal climatic characteristics with opportunity in different seasonal periods of production (FIRA, 2016). In states such as Sinaloa or Sonora, varieties that adapt to warm conditions are being sought in order to improve profitability (González, 2013).

The cranberry is one of the species recently introduced in the agri-food chain in Mexico, its production dates back to 1996 and in the last decade it has grown by more than 800%, due among other factors to the demand of the product in Europe, Asia and North America (Pérez, 2018). In the country there are 2 625 ha of cranberry (SIAP, 2017) that generate between 100 and 110 thousand direct and indirect jobs (FAOSTAT, 2017). The state of Jalisco ranks first in cranberry production, with 14 563 t in 1 576 ha and a production value of 524 million pesos (SIAP, 2017).

In general, the producer price per ton of cranberry amounted to 51 966 pesos in that year and was the highest compared to the rest of the berries. This type of crops, due to its high value, enhances the profitability of small areas, so the integration of small producers is viable (FIRA, 2016). Mexico produces 8.78 t ha^{-1}, positioning itself as the country with the best performance, followed by Italy with 7.5 t ha^{-1}, Romania 6.66 t ha^{-1} and the United States with 6.46 t ha^{-1} (Hernández and Gutiérrez, 2013).

Cranberry is grown from 600 to 2 500 meters above sea level in various parts of the world (Paredes, 2010). In general, the cranberry plant during the autumn in cold climates, has a period of dormancy due to the presence of low temperatures and short photoperiod, which requires a certain number of cold hours (HF) for the floral initiation and growth of leaves in the spring (Retamales and Hancock, 2012). Current available varieties have cold requirements from 150 to 800 HF in southern highbush cranberry, up to 800 to 1200 HF for the northern highbush type, and 300 to 600 HF in varieties type 'rabbit eye' (ojo de conejo) (Retamales and Hancock, 2012).

Likewise, cranberry varieties are classified into three groups: 'high' requirement greater than 800 cold hours, 'medium' requirement of 400 to 600 HF and 'low' requirement, less than 400 HF (García, 2011). It has been proposed to consider that the HF requirements for cranberry are satisfied in the temperature range above 1.4 and below 12.4 °C (Retamales and Hancock, 2012). Cesaraccio *et al*. (2004 and 2006) described the importance of the accumulation of cold followed by a warm period which allows the emergence of reproductive shoots in cranberry. Therefore, the calculation of the HF is important, since it allows to define the potential cultivation sites (Mainland, 1985).

The cranberry despite being a species adapted from temperate and cold climates, production in Mexico is possible because some varieties such as ‘Biloxy’, ‘Victoria’, ‘Kester’, ‘Rocio’ and ‘Corona’ among others, have low requirements of cold hours and adapt to most of the tropical and subtropical microclimates present (Salgado *et al*., 2018). Currently, new cranberry varieties have been introduced to our country that do not require cold hours, and have been selected for always green production systems, such as BiancaBlue™ ‘FCM12-087’, AtlasBlue™ ‘FCM12-045’ and Jupiter Blue ‘FCM12-131’ by the company Fall Creek Farm & Nursery Inc., which will undoubtedly favor further expansion of cranberry cultivation in subtropical and tropical areas.

The precocity of production is the main commercial advantage of low demand cranberry varieties, whose fruits reach the highest prices during the beginning of the harvest of the northern hemisphere in March-April (Cantuarias-Avilés *et al*., 2014). Given the current and future expansion of cranberry cultivation in the state of Nayarit, it is important to have a technical instrument, scientifically validated to identify the areas with climate potential that this crop requires. The objective of the present study was to identify and quantify the surface with optimal agroclimatic conditions for cranberry production in the state of Nayarit.

The results contribute to a better understanding of the environmental conditions that prevail in agroecological zones and is a useful tool for decision makers, technicians and producers.

Materials and methods

Study area

The work considered the territory of the state of Nayarit, an entity located in western Mexico. Located in, between the parallels 23° 05’ 04’’ and 20° 36’ 12’’ north latitude and between the meridians of 103° 43’ 15’’ and -105° 45’ 37’’ west longitude (INEGI, 2015).

Meteorological data

Data from the network of agrometeorological stations in Nayarit were used, which consists of automated equipment that collects fifteen minute data on temperature, precipitation, solar radiation and wind (Adcon Telemetry, model A753, Klosterneuburg, Austria). The network operated for eight years since 2007 with 38 stations (Table 1).

Table 1. Description of weather stations.

Name	Latitude	Longitude	Altitude (m)	Name	Latitude	Longitude	Altitude (m)
Acaponeta	22.48	105.403	15	Santa María del Oro	21.341	104.635	1084
Estancia de los López	20.852	104.434	892	Colonia Moderna	21.467	104.66	858
Valle de Banderas	20.784	105.242	62	Villa Juárez	21.695	105.392	57
El Capomo	21.116	105.156	40	Santiago Ixcuintla	21.824	105.184	10
Ixtapa de la Concepción	21.301	105.192	20	El Verdineño	21.702	105.132	43

Name	Latitude	Longitude	Altitude (m)	Name	Latitude	Longitude	Altitude (m)
Monteon	20.974	105.306	21	Santa Cruz	21.979	105.579	1
Compostela	21.231	104.884	861	Pozo de Ibarra	21.872	105.276	32
Mesa del Nayar	22.214	104.647	1403	Quimichis	22.368	105.537	9
Huajicori	22.636	105.331	75	El Limón	22.301	105.467	3
Ixtlan del Río	21.024	104.362	1131	San Felipe Aztatan	22.399	105.395	22
Rosa Blanca	21.118	104.358	1936	Atonalisco	21.653	104.827	415
Puente de Camotlan	21.7	104.089	1113	V. Carranza	21.525	104.974	1063
Rosamorada	22.095	105.217	25	Xalisco	21.425	104.892	974
Guadalupe Victoria	21.667	105.326	3	Malinal	21.367	105.018	864
Las Palmas	21.605	105.143	186	San Pedro L.	21.201	104.757	1271
Tequilita	21.104	104.807	979				

Data management

Using the Access 2013 database engine (Microsoft Office 2010, Redmond, Washington, United States), the temperature data organized by weather station, date and time were integrated.

Calculation of accumulated cold hours

For each meteorological station, month and year, cold hours (HF) were quantified. The HF are the records of temperature less than or equal to 12 °C. This temperature threshold was suggested by Norvell & Moore, 1982. The calculation was made using the following equation:

$$HFAm = (\Sigma RT \leq 12\ °C)/ 4$$

Where: HFAm are the cold hours accumulated per month and RT are the fifteen minute temperature records less than or equal to 12 ºC.

Annual cold hours data set

For the analysis of the annual data (HFA) the monthly values were averaged for the time series (8 years) for each station. Two databases were obtained, one for the interpolation constituted by the registries of 31 stations and the other with registers of seven stations, representing a sample of 20% for the validation of the interpolation (Table 1).

Cartographic representation

The spatial analysis was carried out in the geographic information system Arcmap Version 10.1 (ArcGIS ESRI, Redlands, California, United States). The interpolation method used for the HFA variable was IDW (Weighted Reverse Distance) and the result of this procedure was classified according to Table 2.

Table 2. Classification of the accumulation of annual cold hours and varieties of cranberry suitable for that condition.

Threshold		Description and conditions of cold hours by variety[1]
Lower	Upper	
0	299	Insufficient cold hours accumulation for many varieties, except varieties for evergreen cultivation, with low or no cold requirement. For example, Biloxi (150 HF), Victoria (no cold requirement)
300	399	Conditions for varieties Jewel, Rabbiteye and Misty
400	499	Conditions for varieties Sharblue and O'Neal
500	699	Conditions for varieties Jubilee and Ozarkblue

[1]= (Norvell y Moore, 1982; Darnell and Davies, 1990; Darnell, 1992; Garcia, 2011; Salgado *et al.*, 2018).

The map of the annual accumulation of cold hours in Nayarit was elaborated in Arcmap Version 10.1, with the spatial statistical method ArcToolBox the state and municipal surface for each class was calculated.

Validation of the interpolation

Accumulated cold hours data resulting from interpolation or predicted data were compared against the observed data from a random sample of seven stations (Table 3). With the statistical program Minitab version 17 (State University of Pennsylvania, United States), the analysis was developed with the linear regression model, calculating the correlation coefficient.

Table 3. Description of meteorological stations used in the validation.

Name	Latitude	Longitude	Altitude (m)
San Juan de Abajo	20.837	105.211	70
Las Varas	21.192	105.147	14
Jala	21.081	104.438	1 045
Huajimic	21.671	104.342	1 205
Amapa	21.812	105.232	31
Tecuala	22.4	105.475	11
Tepic	21.488	104.89	946

Analysis of the monthly data set. An analysis of descriptive statistics of the daily data organized by month was carried out, with the support of a cash chart elaborated with the statistical program Minitab version 17.

Results and discussion

Accumulated annual cold hours of the study area

In Nayarit, 72.6% (2 038 724 ha) of the territory accumulates less than 300 cold hours annually. The remaining 768 549 ha accumulate from 300 to 700 cold hours annually, which according to (Norvell and Moore, 1982; INTAGRI, 2017; Salgado *et al.*, 2018) are sufficient for the production of cranberry varieties of 'Rabbit Eye' , as well as southern high shrub type Jewel, Misty, Sharpblue, O'Neal, Jubilee or Ozarkblue (Figure 1).

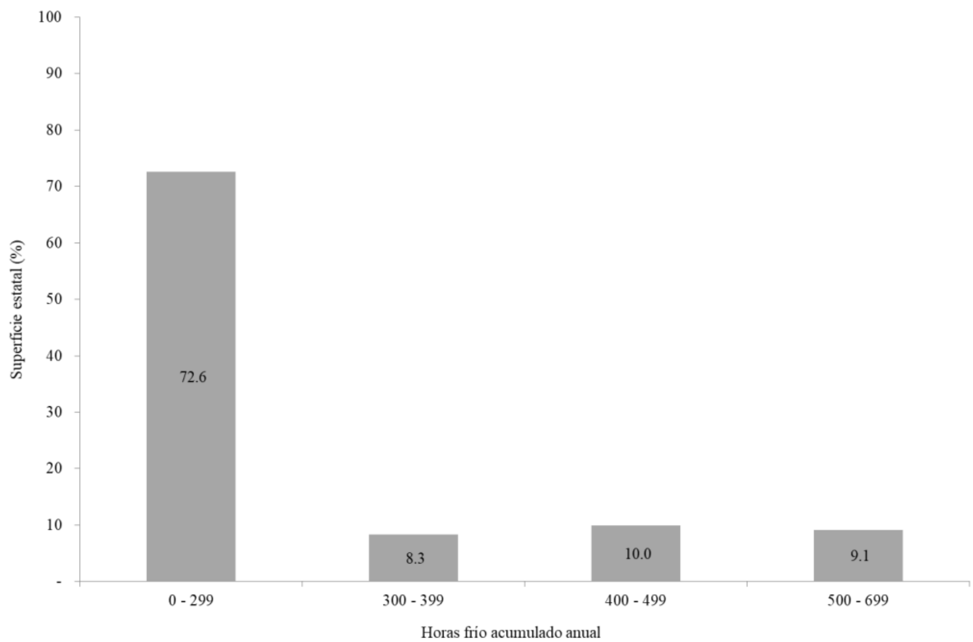

Figure 1. Classification of annual accumulated cold hours in Nayarit.

The conditions identified between 300-500 HF per year, which represent 18.3% of the state area, may be suitable for the Biloxi variety, which coincides with Salgado *et al*. (2018). The HF demanded by some varieties of cranberry of low and medium cold requirement according to García (2011) were found in the present work, so in Nayarit it is highly feasible to grow it.

Annual accumulation of cold hours by municipality

In 19 municipalities it was possible to quantify surface area where less than 300 cold hours accumulate annually. The 768 549 ha corresponding to the accumulation of cold greater than 300 annual hours were located in the municipalities of Ahuacatlan, Amatlan de Cañas, Compostela, Del Nayar, Ixtlan del Río, Jala, La Yesca, San Pedro Lagunillas, Santa María del Oro, Tepic and Xalisco. The surface in which they accumulate more than 500 cold annual hours corresponds to the municipalities of Ahuacatlan, Del Nayar, Ixtlan del Río, Jala, La Yesca, San Pedro Lagunillas, Santa María del Oro and Tepic, which represents 256 125 ha, 9.1% of the state territory. Of these, the municipalities of La Yesca and Santa María del Oro stand out with about 180 000 ha (Table 4).

Table 4. Area in hectares with cold hours accumulated during the year.

Municipality	Annual accumulation of cold hours			
	0-299	300-399	400-499	500-699
Acaponeta	142 610.4			
Ahuacatlán	25 469	13 323.9	8 024.3	3 623.2
Amatlan de Cañas	50 266	1 529.9		
Bahia de Banderas	77 073			

Municipality	Annual accumulation of cold hours			
	0-299	300-399	400-499	500-699
Compostela	152 478.1	7 785.8	27 642.2	
Del Nayar	489 687.3	10 008.8	6 660.3	7 482.5
Huajicori	223 538.3			
Ixtlan del Río	4 010.6	26 943.6	3530.5	14 781.9
Jala		38.6	941.7	49 344.4
La Yesca	6 824.3	147 103.3	185 904.5	91 569.4
Rosamorada	183 914.7			
Ruiz	52 016.5			
San Blas	110 328.9			
San Pedro Lagunillas	44 050.7	5 308.4	1 928.8	237.9
Santa María del Oro	2 275.8	8 484.5	11 295.3	86 998.3
Santiago Ixcuintla	172 747.4			
Tecuala	104 399.2			
Tepic	137 124.8	8 884	15 294.6	2 086.7
Tuxpan	31 367.6			
Xalisco	28 541.4	3 088.4	18 703.5	

García (2011), classified the requirements of HF for cranberry in: low (<400), medium (400-600) and high (>800), the previous corresponds to our study to 8.3% and 19.1% of the state surface of the low and medium level respectively.

Spatial distribution of the annual accumulation of cold hours

In Figure 2, it was observed that the region where less than 300 HFA accumulates are distributed throughout the coast, the municipalities from Tepic to Huajicori to the north and in the south, the San Pedro Lagunillas region, the south of Ahuacatlan and Amatlan de Cañas. The region with optimal conditions is concentrated in the center and south of the state, mainly in the municipalities of Santa Maria del Oro, Jala, north of Ixtlan del Río and south of La Yesca.

The geographic information system allowed the cartographic representation of climatic data, as well as quantifying the surface of the four classes of annual HF accumulation in Nayarit. The results will allow locating the areas with better conditions for the establishment of crops with specific thermal requirements, such as the cold hours in cranberry, similar investigations were reported by Bhatt *et al*. (2018); Gentilucci *et al*. (2019) for kiwi (*Actinidia deliciosa*) in India and grape for wine (*Vitis vinifera*) in Italy respectively. On the other hand, Paredes (2010) points out that cranberry is successfully grown from 600 to 2 500 masl, which is consistent with our results, particularly with the zones with annual accumulation of cold hours >400 that are located at altitudes of 900 to 2 000 m.

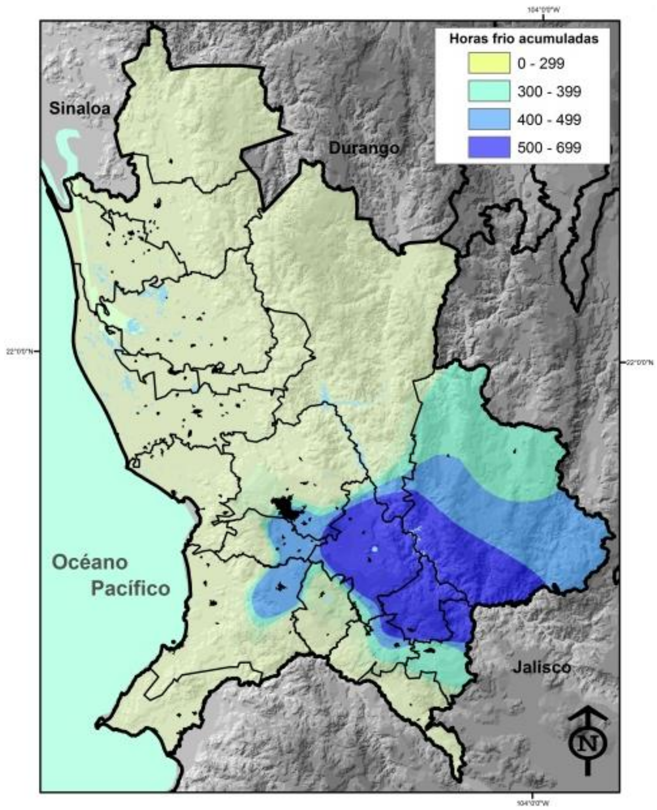

Figure 2. Spatial distribution of the annual accumulation of cold hours in Nayarit.

Validation of the interpolation model

In Figure 3, the result of relating the data generated by the interpolation of the IDW model (predicted) with the observed ones is shown. In 71.4% of the validation points, interpolation underestimates (residues less than 25 cold hours), even so, the adjustment of the model with a correlation coefficient of 0.97 is very good, only in two validation points the interpolation overestimates with residuals from 9.9 to 16.9%.

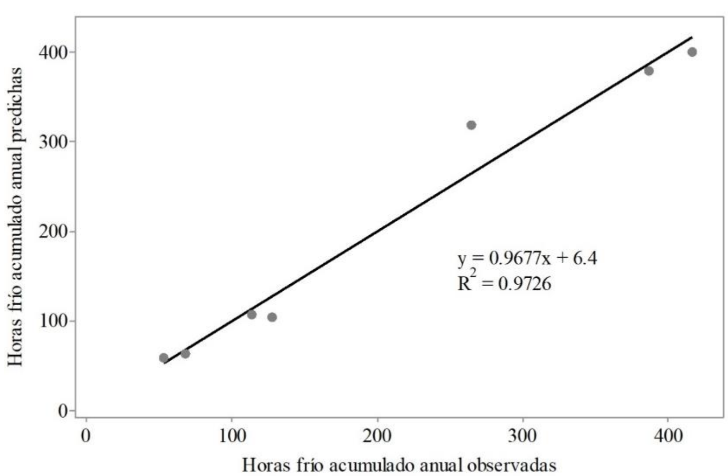

Figure 3. Correlation between the values observed and predicted by the interpolation of annual accumulated cold hours.

The results contrast with that reported by Alzate-Velásquez *et al*. (2018), where they evaluated the IDW interpolation model with an R^2 of 0.76, in this study the regression model reported better results with 0.97 in R^2. Yang *et al*. (2015) reported results similar to those of the present work, when evaluating the precision of the same interpolation model (R^2 of 0.94).

Monthly distribution of cold hours

In the region where more than 300 HF is accumulated per year, the largest monthly variation occurs in November and December (with average values >60 HF), being the months when the period of greatest accumulation of HF starts from November to March. In this same period, 50% of the data fluctuates between 40 and 115 HF, indicating a high interannual variability in the region. The lowest accumulation occurred between June and September (average >15 HF), initiating a decline in HF in April (50 average HF) until reaching the lowest accumulation in June with 8.6 HF (Figure 4).

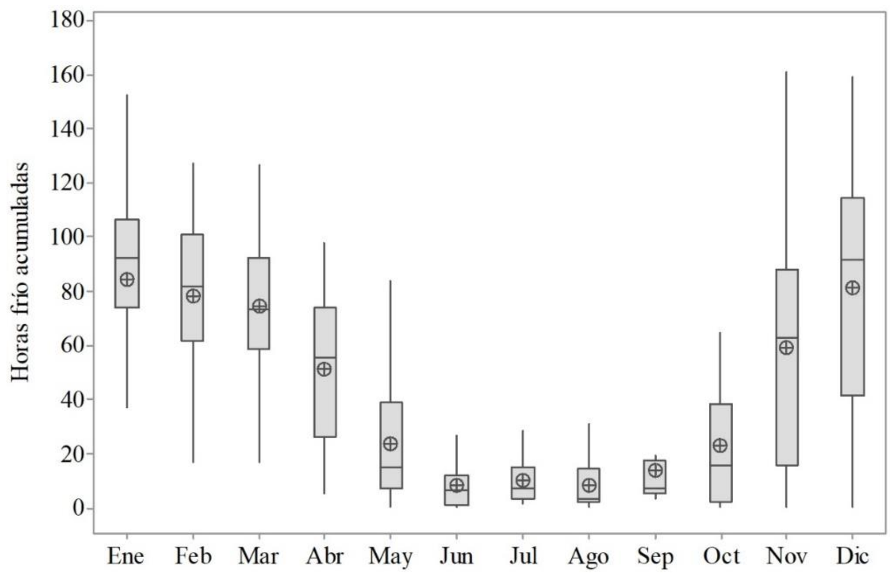

Figure 4. Monthly distribution of cold hours for the region with more than 300 HFA.

Conclusions

For the first time in Nayarit, it was possible to identify and quantify the surface with optimal agroclimatic conditions to produce cranberry. The number of cold hours accumulated annually allows the production of commercial varieties of low requirement. Considering the good precision of the interpolation model, the optimal conditions are found in 27% of the state surface (700 thousand hectares) distributed in 11 municipalities.

The period that accumulates the coldest hours in Nayarit is from November to March. These results will serve for the design of a strategy of productive reconversion of soils with low productivity, no agricultural aptitude or idle condition; to move towards a crop of high commercial value that demands labor and services associated with the value chain.

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