








Anthocyanins in local, healthy and specialty agrifood from the Sierra Nevada of Puebla

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ABSTRACT

Objective: to quantify anthocyanins in blue maize, raspberry, and blackberry fruit, grown in family systems in three localities of the Sierra Nevada in Puebla, in order to know the local perception and valuation of those compounds.

Design/Methodology/Approach: during 2024-2025, a mixed methodology was applied in the selected localities (San Mateo Ozolco, San Miguel Tianguizolco and San Diego Buenavista, in the state of Puebla, Mexico). Anthocyanins were quantified in five samples per culture using Ultraviolet-Visible spectrophotometry, analysis of variance and Tukey ($p \leq 0.05$). To evaluate perception, 45 surveys were applied following a non-probabilistic convenience sampling in local agrifood fairs.

Results: high anthocyanin contents were recorded; blackberry fruit ($5733.6 \text{ mg kg}^{-1}$), raspberry (923.9 mg kg^{-1}), and blue maize ($673.5\text{-}893.7 \text{ mg kg}^{-1}$); all above what is recommended for nutraceutical effects. A 76% of partially informed consumers was identified, with a willingness to pay a premium for agrifood, proven it is rich in anthocyanins.

Limitations/Implications of the study: it is necessary to expand this analysis to more regions and to consider agronomic variables, processing and bioavailability; in addition to promoting socialization strategies that translate scientific evidence into socioeconomic and food value, strengthening the rural economy and consumption.

Findings/Conclusions: blue maize and berries grown in family systems have high nutraceutical and socioeconomic value that can be used as an agri-bio-cultural heritage in rural farming economy, through sustainable rural and indigenous production schemes.

Keywords: functional agrifood, nutraceuticals, cyanidin-3-glucoside (C3G), local perception, socioeconomic value.

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INTRODUCTION

The hegemonic global agrifood system has transformed production and consumption, displacing local agrifood with ultra-processed products. These latter are harmful to health, environment, culture and local economies; as they have high content of refined sugars, salt,



fats and additives. This transition has weakened farming systems, crop diversity, peasant artisanal processes, and marketing; in addition to affecting food culture and aggravating food insecurity (Torres & Rojas, 2024).

The problem is aggravated in rural and indigenous areas that, despite the production of healthy agrifood, have seen its consumption displaced, which have generated food and health problems. In Mexico, 55.5% of households live in food insecurity, with Puebla among the most affected entities according to Mexico's Consejo Nacional de Evaluación de la Política de Desarrollo Social (CONEVAL, 2020). In view of this, there is a growing interest in agrifood such as blue maize and berries known as red fruits or just, berries. They are recognized for their anthocyanins content, which are pigments of the flavonoid group that give reddish, purple and bluish tones, and have nutraceutical properties.

In rural and indigenous communities of the Sierra Nevada in Puebla, berries cultivation and consumption strengthen food security and local economy through sustainable systems and community social participation (Xochipa *et al.*, 2024). In San Diego Buenavista (state of Puebla, Mexico), the second largest locality as producer of berries in the state, more than 11 million Mexican pesos (MMXN) are generated by the selling of 383 tons (Megagrams, Mg) raspberries, and 2.6 MMXN per 103 Mg of blackberry fruits, according to Mexico's Agri-Food and Fisheries Information Service (SIAP, 2024).

In San Miguel Tianguizolco and San Mateo Ozolco, native blue maize represents cultural and linguistic identity (Nahuatl), linked to the ancient farming worldviews (Xochipa-Morante *et al.*, 2024). Although these practices are invisible in official statistics, they yield annually 6825 Mg of berries in the state, cultivated in 1606 hectares (ha) with a value of more than 43 Mmxn according to Mexico's Agri-Food Information System Database under the Secretariat of Agriculture (SIACON, 2023).

Family systems with traditional, transitional, or agroecological management have a direct impact on the concentration of anthocyanins that determine the functional and nutraceutical quality of berries and blue maize. Their sale as raw material, and processed artisanal or semi-industrial products in short-selling circuits (SSC) strengthens direct sales, proximity, trust and exchange of knowledge between producers and consumers. These dynamics promote fair trade, solidarity economy, and access to agrifood with bioactive compounds beneficial to health (Xochipa-Morante *et al.*, 2021). Among those compounds is cyanidin-3-glucoside (C3G), an anthocyanin present in blue maize, raspberry and blackberry fruits.

However, most studies focus on commercial cultivars (Vázquez-Carrillo *et al.*, 2025), leaving aside native and wild species in rural and indigenous contexts. This omission reduces the understanding of the local perception and valuation of these compounds, limiting scientific knowledge, the revaluation of biodiversity, and their incorporation into rural development policies aimed at food security and sovereignty. This security understood as the continuous access to sufficient, nutritious and quality food; and sovereignty, as the character that defends the right of people to decide their own local and sustainable food systems (Xochipa *et al.*, 2024). The problem addressed is the lack of knowledge about the anthocyanin content in those crops, as well as the local perception and valuation of these compounds and their effects on food and health.

This lack of information limits the utilization of crops with high socioeconomic, environmental, and health value. Therefore, the objective is to quantify the anthocyanin content (C3G) in blue maize, blackberry, and raspberry cultivated in three locations of the Sierra Nevada, and to assess the local perception and valuation of these compounds and their consumption.

The hypothesis posits that these agri-foods possess functional and socio-productive properties that can be harnessed within agrobiocultural heritage and Short Food Supply Chains (SFSC).

The study's relevance lies in highlighting the nutraceutical and socioeconomic value of these agri-foods grown in family farming systems, recovering traditional and agroecological practices, and reducing the use of GMOs and agrochemicals. Overlooking them would continue to marginalize knowledge, crops, and territories that are fundamental for transitioning toward healthy, sustainable, and culturally appropriate food systems.

MATERIALS AND METHODS

This study was designed as of mixed type, with both quantitative and qualitative characteristics, in an exploratory and analytical-descriptive approach. It was developed in two stages; the first one was the chemical analysis of native and wild fruit samples. And the second stage was the exploration of perception and valuation on the part of consumers, about agrifood with anthocyanins.

Study area

The study was implemented in three localities of the Sierra Nevada in Puebla (Mexico). San Mateo Ozolco belongs to the municipality of Calpan, while San Miguel Tianguizolco and San Diego Buenavista are in the municipality of Huejotzingo (Figure 1).

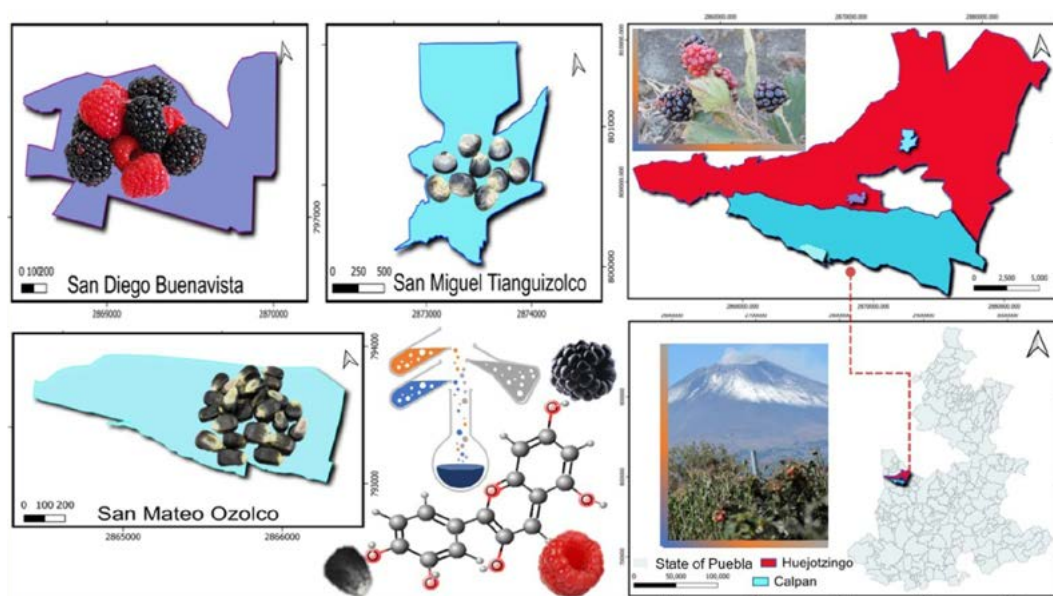


Figure 1. Geographical location of the study area. Source: prepared by the authors in QGIS.

These localities are between 2200 and 2600 m altitude, in a temperate subhumid climate, with fertile volcanic soils and ideal conditions for the cultivation of blue maize (*Zea mays* L.) and berries such as blackberry fruit (*Rubus fruticosus*) and raspberry (*Rubus idaeus*). Production systems are family-based on traditional practices, agroecological practices, or developing in a transitional process between both.

The socio-territorial context includes elements such as migration, marginalization, indigenous population, high levels of food insecurity, and health problems under the criteria of Mexico's National Council for the Evaluation of Social Development Policy (CONEVAL, 2020) and Mexico's National Institute of Statistics and Geography (INEGI, 2020).

Quantification of anthocyanin content

Experimental design. A completely randomized design was applied with a single factor (community) and three replicates per type of crop. In total, 15 samples were analyzed; five native blue maize, five blackberry fruits (Maravilla variety), and five raspberry (Tuppy variety).

Genetic material and sample collection. During the harvest season (November 2024 and May 2025), 200 grams of samples of blue grains and blackberry and raspberry fruits in an optimal state of ripeness were collected for consumption. Harvest was made directly in the plots of the farmers.

Sample preparation and anthocyanin extraction. These procedures were done in the Laboratorio de Instrumentación de Alimentos, under the Universidad Tecnológica de Huejotzingo (UTH), following the methodology of Mendoza-Mendoza *et al.* (2017).

Blue maize. Sampled grains were dried at a temperature of 70 °C in a Felisa[®] stove, then pulverized in a Wiley[®] stainless steel mill, with a 2-mm mesh test sieve, until a homogeneous flour was obtained.

Berries. The fruits were dried at 65 °C in a Felisa[®] oven, then ground to a particle size of 1 mm in diameter for preservation.

Extraction. It was made using 70% acidified methanol with 1% hydrochloric acid (HCl), at room temperature for 15 minutes. The solutions were then vacuum filtered with Whatman No. 1 filter paper. The residue was washed with 10 mL of acidified methanol and measured at 50 mL with buffer solutions of potassium chloride (KCl) pH 1 and sodium acetate (CH₃-COONa) pH 4.5, then the corresponding dilutions were carried out ensuring that the dilution for both samples had an absorbance lower than 1.0 and in the range of 0.4 to 0.6. The samples were stored at -20 °C until analysis. The reagents and solvents used were Sigma-Aldrich[®] and JT Baker[®] analytical grades.

Spectrophotometric quantification, calculations and statistical analyses. The differential pH method proposed by Wolstrad (1976) was used, spectral measurements were made on a single-beam UV-Visible spectrophotometer (CARY 50 Conc) at 515 nm and 700 nm in triplicate.

The total anthocyanins concentration (TAC) was calculated as cyanidin 3-glucoside mg kg⁻¹ of dry matter (DM) of grain or fruit flour, according to the formula of Mendoza-Mendoza *et al.* (2017). A descriptive analysis was performed, followed by an analysis

of variance to compare differences between communities by crop and the Tukey test to identify those means that were significant ($p \leq 0.05$). All analyses were executed in SPSS[®] v.26.

Local perception on anthocyanins and consumption valuation

During 2024-2025, 45 surveys (15 per crop) were applied to frequent consumers of blue maize, raspberries and blackberries in short selling circuits (SSC) of agrifood. The sampling was non-probabilistic for convenience, applied in representative local fairs: the berry fair (Buenavista), the maize fair (Tianguilco) and the pulque fair (Ozolco), the latter with a strong presence of blue maize.

The questionnaire included questions on knowledge of the term ‘anthocyanins’ and assessments associated with its consumption. Data were captured in Microsoft[™] Excel[®] and analyzed with descriptive statistics (frequencies, means, standard deviations) with SPSS[®] v.26. Analysis results were represented in graphics, and data frequencies, in word clouds.

RESULTS AND DISCUSSION

Anthocyanin content

We recorded concentrations of cyanidine 3-glucoside (C3G) in blue maize, raspberry and blackberry fruit from the Sierra Nevada in Puebla (Mexico). Our results showed that blackberry fruit had the highest anthocyanin content value (5733.6 mg kg⁻¹ DM), followed by that of raspberry (923.9 mg kg⁻¹ DM), and blue maize (673.5-893.7 mg kg⁻¹ DM) in third place (Table 1).

These findings coincide with those of Castañeda-Cardona *et al.* (2024), with 7780 mg kg⁻¹ DM in blackberries and 880 mg kg⁻¹ in raspberries. Also they coincide with those of Kim *et al.* (2021), who reported 11 500 and 2500 mg kg⁻¹ DM in blackberries and raspberries, respectively. This confirms the high accumulation capacity of anthocyanins in blackberry fruit. In this study, the varieties Tuppy and Maravilla, together with the production system in agroecological transition, were able to influence the levels recorded in raspberry and blackberry fruit.

In blue maize, in Tianguilco we found a higher concentration (893.7 mg kg⁻¹) than in Ozolco (673.5 mg kg⁻¹). These differences can be attributed to factors such as altitude,

Table 1. Concentration of 3-glucoside cyanidine (C3G) in agrifood, per locality and per crop, in three localities of Puebla (Mexico).

Crop	Locality	Mean (mg C3G kg ⁻¹ DW)	Range (mg C3G kg ⁻¹ DW)	Production System
Blue maize	Ozolco	673.46 ± 73.80 B	551.8-726.4	Agroecological
	Tianguilco	893.66 ± 13.33 A	728.5-1002.4	Traditional
Raspberry	Buenavista	923.88 ± 133.75 B	789.0-1123.0	In agroecological transition
Blackberry fruit		5733.56 ± 539.63 A	5070.2-6487.5	

Values are expressed as mean ± standard deviation (n=5). DW: dry weight (biomass). Means with different letters indicate significant difference (Tukey; $p \leq 0.05$).

local variety, agricultural practices, soil management, and especially to the availability of nitrogen and phosphate, both of which are critical in anthocyanin synthesis.

The grain of the traditional system presented higher C3G than the agroecological grain of Ozolco, possibly due to the use of mineral fertilizers (N-P-K), DAP (diammonium phosphate), UREA and Triple 18, which stimulate the PAL, F3H, DFR enzymatic pathways, associated with the synthesis of anthocyanins (Feng *et al.*, 2024).

In agroecological systems with the application of organic fertilizers (compost, manure) and foliar fertilizers, nitrogen is released slowly, levels may be suboptimal, which does not allow to achieve similar values of accumulation of anthocyanins. Nonetheless, these results show that both family-based systems, traditional and agroecological, can generate functional agrifood with high nutraceutical value.

Local perception about anthocyanins and consumption valuation

The surveyed participants were mostly women (62%), with an average age 40.6 ± 10.8 years old (range, 21-66 years), their level of education is predominantly a bachelor degree. Among the products valued are those with native blue maize in value-added presentations such as tostadas, tortilla chips and baked nachos, and freshly made tlacoyos. As for berries, their consumption is mainly fresh and seasonal, with purchases made in short cycles, either weekly, monthly, or occasionally.

Local knowledge of the term ‘anthocyanins’

Of the interviewees, 47% have heard the term ‘anthocyanins’, this indicates an initial but significant knowledge about these compounds. The other half of participants is unaware of this concept, thus reflecting there is a gap between scientific knowledge and everyday knowledge. So, consumers’ profile feature is defined as ‘partially informed’ (Figure 2).

This lack of knowledge contrasts with the scientific relevance of anthocyanins, since the impact of these substances on health is widely documented. It also reinforces the need for accessible dissemination strategies that bring scientific evidence closer to local contexts (urban and rural).

When we asked which word they associate anthocyanins with, the most frequent answers were ‘antioxidants’ in the case of berries, and ‘pigments’ in blue maize. Other

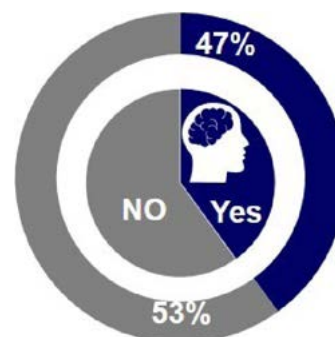


Figure 2. Knowledge of the participants on the term, by answering the question “Have you heard of anthocyanins?”

general terms, such as ‘healthy’ and ‘nutraceuticals’ were also recorded, although their specific functions were not clearly identified by the participants (Figure 3).

These associations reflect a basic, largely intuitive and non-technical understanding. Although there is valuable local knowledge, it is fragmentary and empirically linked to well-being and healthy food. This perception represents an important basis to be strengthened, through food education actions, as well as through diversification of products and territorial development (Xochipa *et al.*, 2024).

Criteria for traditional valuation associated with consumption

Consumption of this agrifood occurs mainly in SSCs (specialty niches, healthy markets, agrifood fairs, traditional cuisines and direct sales on the farm), which strengthens the link between origin, perceived quality and consumer confidence. This dynamic facilitates direct communication between producer and consumer, also creating strategic opportunities to introduce precise knowledge on concepts such as ‘anthocyanins’ and the health benefits with which they contribute to human health, as ‘functional foods’.

We summarize here the evaluation criteria recorded with a higher frequency in the responses of surveyed participants for the evaluated agrifood.

The main reasons for consumption are organoleptic properties —taste, color, texture, consistency, flexibility, freshness— (80%); followed by nutritional properties (11%), perceived health benefits, origin (native creole maize); finally, because of tradition, artisanal production, and freshness. This combination reveals that there is a tangible appreciation of functional qualities, even without formal knowledge about its bioactive compounds.

It is worth noticing that 76% of consumers declared to be willing to pay a premium between 5% and 30%, if it is guaranteed that these products contain anthocyanins beneficial to health, while the remaining 24% expressed economic limitations or mistrust. This willingness-to-pay represents an opportunity to differentiate products, especially those made with blue grains rich in anthocyanins. For this reason, it is key to quantify their



Figure 3. Words associated with the concept ‘anthocyanins’ in berries and blue maize. Source: word clouds created in atlas.ti, with data from the field survey.

Table 2. Valuation associated with the consumption of blue maize and berries in San Mateo Ozolco, San Miguel Tianguizolco and San Diego Buenavista (Puebla) Mexico.

Variable	Blue maize from Ozolco	Blue maize from Tianguizolco	Berries from Buenavista
Site of purchase	Specialty niches (healthy markets & stores, organic & gourmet) (40%) Production unit (40%) Fairs (13%) Traditional cuisines	Urban markets and street markets 87% Production unit: 13%	Supply market (33%) Direct sales on farm (27%) Healthy store (27%) Fairs (13%)
Reason for consumption	Organoleptic properties (45%) Beneficial to health (33%)	Organoleptic properties (60%) Creole maize (origin), artisanal tradition.	Organoleptic properties (75%) Beneficial to health (25%)
Are you willing to pay more for the benefit of agrifood rich in anthocyanins?	Yes (80%) No (20%)	Yes (73%) No (27%)	Yes (73%) No (27%)
Additional payment	17.5 ± 7.2% (5-30%)	11.0 ± 7.4% (3-30%)	14.6 ± 4.2% (10-20%)

content after processing, to communicate it then through innovative labeling, since these compounds provide competitive value in specialty niches interested in functional foods and nutraceuticals.

CONCLUSIONS

Anthocyanin content [cyanidin, 3-glucoside (C3G)] in blackberry fruit, raspberry and blue maize grown in the Sierra Nevada in Puebla (Mexico), reached levels with nutraceutical effects. This confirms potential as functional and nutraceutical agrifood with strategic value. The variations observed reflect the influence of local production systems, variety and local agro-environmental condition.

The importance was highlighted of integrating the traditional knowledge of rural farmers and agroecological approaches in the use of these compounds. Partially informed consumers were identified, with willingness-to-pay a premium for products with anthocyanins in short-selling circuits. A diversification of products requires for attractive labeling strategies, food education and health prevention processes to strengthen the linkage between producer and consumer.

Blue maize and berries are key resources for productive diversification, to the strengthening of agro-bio-cultural heritage and development of solidarity economies for rural farmers. It is recommended to research stability and bioavailability of anthocyanins, also, on healthy food strategies with a territorial approach. It is required as well, to translate scientific knowledge into practical and communal benefits towards creating fair, sustainable and culturally relevant agrifood systems.

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