Article

Purple corn cultivars of high yield and with high content of anthocyanins in the Cajamarca region, Peru

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Abstract

Purple corn contains anthocyanins as its main secondary metabolite, which belong to the group of polyphenolic flavonoids, responsible for many biological activities, mainly high antioxidant activity. The aim is to identify purple corns with good grain production and anthocyanin content in the cob and bracts that generate more income for producers from the Cajamarca region in Peru, using three cultivars in four localities in the Cajamarca region of Peru. The results show that the best production environment was Chala, where the highest grain production was recorded, it was in the cultivars INIA-601 (4.38 t ha^{-1}) and MM (3.75 t ha^{-1}). The same cultivars had the highest concentrations of anthocyanins in both the cob and bracts, with values of 7.9 and 4.53 mg g^{-1} for INIA-601 and 7.2 and 2.1 mg g^{-1} for MM, respectively, which suggest them as potential varieties due to the high yield and content of anthocyanins.

Keywords: agronomic behaviors, Peruvian Andes, phytochemicals, purple corn.

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Introduction

Purple corn (*Zea mays* L.) is native to the Andes region of Peru. It is widely cultivated and consumed throughout the Andes region of South America, mainly in Peru, Ecuador, Bolivia and Argentina (Lao *et al*., 2017). Peru exported 0.006755 tons of purple corn for a Free On Board (FOB) value of US$12 550 179 in 2020, figures that show an exponential increase from the 798 810 kilos exported in 2019 for US$1 249 588. Purple corn exports have the United States of America as their main destination, where placements for US$6 886 733 (55% of total shipments) were achieved, followed by Spain with US$1 693 687 (13%), Ecuador with US$1 281 573 (10%), Belgium with US$637 702 (5%) and other countries with smaller amounts that totaled US$2 050 485 (Agrodataperu, 2021).

Purple corn is recognized by the European Union (EU) and Japan under the code E-163 and under the international numbering system INS-163iv (Lao *et al*., 2017). Peru has many cultivars, some local such as Canteño, Cuzco, Caraz, Arequipeño, Negro de Junín, others from the National Institute of Agrarian Innovation (INIA, for its acronym in Spanish) such as cultivars INIA-601, INIA-615 Negro Canaán, the experimental improved corn called MM and other cultivars from the La Molina National Agrarian University (UNALM, for its acronym in Spanish) such as PM-581 and PM-582 (Manrique, 1997; Pedraza *et al*., 2017). Purple corn is the only one in the world for having grains, cob and bracts from purple to black due to the amount and type of anthocyanins they have.

Anthocyanins, which are the most important pigments of purple corn, are water-soluble compounds that, from the chemical point of view, are a glycosylated polyhydroxylated or polymethoxy molecule derived from 2-phenylbenzopyril, belonging to the large group of flavonoids and this within the group of polyphenolic phytochemical compounds (Martin *et al*., 2012). From another point of view, anthocyanins have a glycosylated form of anthocyanidins and the most abundant is cyanidin-3-O-glucoside (C3G) with 45.8% relative abundance, followed by cyanidin-3-O-(6malonylglucoside) with 40.1% and, in smaller proportions of relative abundance, compounds of the family of pelargonidin and peonidin have been identified (Chen *et al*., 2016).

The functions of anthocyanins in plants are multiple, from protecting against UV radiation, attracting pollinating insects to preventing fruit freezing (Gorriti *et al*., 2009 and Guillen-Sánchez *et al*., 2014). This phytochemical is widely used in the food industry as a base element to produce functional foods (Mansilla and Nazar, 2020), in the cosmetic, pharmaceutical and medicine industries. In addition, the extensive biological activity has been verified, mainly in antioxidant activity (Tian *et al*., 2018; Tian *et al*., 2019), inhibiting reactive oxygen molecules (ROS), which are the product of cellular metabolism and exogenous sources such as X-rays, tobacco smoke and environmental pollution (Sánchez-Valle *et al*., 2013).

Anthocyanins have many benefits on human health, for example, they decrease obesity and inflammation (Lee *et al*., 2017), prevent atherosclerosis, cardiovascular and cellular aging problems (Zhang *et al*., 2019), in addition, they are antimicrobial (Ccaccya *et al*., 2019) and are recommended for their anti-inflammatory effect, help in the formation of collagen and elastin, maintain cholesterol levels in the blood, help in the synthesis of fatty acids favoring people with diabetes (Zhang *et al*., 2019; Ferron *et al*., 2020; Cristianini and Guillen, 2020), prevent cancer of esophagus, colon, lung, prostate and skin (Khoo *et al*., 2017; Lao *et al*., 2017; Sheng *et al*., 2018), and are an antimutagen (Lao *et al*., 2017). The objective of this research work was to evaluate grain production and anthocyanin content present in cob and bracts using the cultivars INIA-601, MM and Canteño in four localities belonging to the Department of Cajamarca.

Materials and methods

Plant material

Three cultivars of free-pollinated purple corn were evaluated, which were INIA-601, Morado mejorado (MM) and Canteño, whose characteristics are explained in Table 1.

Table 1. Characteristics of the varieties INIA-601, MM and Canteño evaluated in the 2018-2019 cycle.

Cultivar	Race/improved variety	Grain color	Adaptation zone	Source
INIA-601	Improved variety	Intense purple	Adapted in the northern highlands of Peru, in the Departments of Cajamarca, La Libertad and Piura, their altitudes range from 2 490 to 3 175 m	Pedraza *et al*. (2017)
MM	Improved variety	Dark purple	It is a synthetic variety derived from INIA-601, this cultivar has been selected by the Baños del Inca EAS of INIA, which uses a selection of S_1 progenies.	Medina-Hoyos (2020)
Canteño	Race	Purple to black	It is grown in the upper parts of the valley of the Chillón River in the Department of Lima, between 1 800 and 2 500 m	Manrique (1997)

Trial site

The trial was carried out in the Department of Cajamarca in four localities, which are Tartar Chico, Shaullo Chico, Iglesiapampa and Chala, their geographical location is shown in Table 2 (Weather Underground, 2020). The agricultural campaigns in the four localities were carried out from October 2018 to April 2019.

Table 2. It shows the geographical data in the four localities evaluated in the Department of Cajamarca in Peru.

Province	District	Locality	Geographical location	Altitude	Average temperature	Average precipitation	Type of climate
Cajamarca	Baños del Inca	Tartar chico	7°8’40.8’’ S, 78°27’50.9’’W	2 690 m	10.4 °C as minimum temperature and 31.4 °C as temperature	2 963 mm	From warm to temperate. There is more rainfall in summer than in winter.
		Shaullo chico	7°10’24” S, 78°26’33.1” W	2 789 m			
San Pablo	San Pablo	Iglesiapampa	7°7’6.7” S, 78°47’43.6” W	2 575 m	14 to 30 °C	2 701 mm	From warm to temperate. There is rainfall all year round.
Hualgayoc	Bambamarca	Chala	6°40’44” S, 78°31’2” W	2 580 m	12 to 32 °C	930 mm	In summer, it is hot and arid, mostly cloudy, and in winter, it is dry and clear.

Field management and experimental design

The block design was completely random, with a sowing density of 50 000 plants ha^{-1}. The experimental unit consisted of five furrows established at 80 cm between furrows, 50 cm between holes, placing two seeds per hole. Each of the furrows was 5.5 m long and the number of experimental units was 4. Fertilization in the four localities was used in the form of N-P-K, its chemical composition is N, P_2O_5 and K_2O, respectively, it was in Tartar chico (165, 45, 65), Shaullo chico (120, 60, 50), Iglesiapampa (120, 60, 50) and in Chala (145, 65, 45) kg ha^{-1}, respectively. The fertilization was made with island guano twice, the first application was at sowing and the second at ridging.

In all experimental units, pests such as fall armyworm (*Spodoptera frugiperda* Smith) and earworm (*Helicoverpa zea* Boddie), were controlled. Evaluations were conducted in the three central furrows and ten plants per treatment were randomly selected. The biometric variables analyzed were: days of female and male flowering, taken from 50% of plants releasing pollen and showing pistils, plant and ear height in meters, prolificacy, defined as the number of ears/plants, ear rot in (%), using a scale from 1 to 6 established by the Maize Program of the International Maize and Wheat Improvement Center (CIMMYT, 2004) and root and stem lodging, both expressed in (%).

The agronomic variables were: field weight, (%) of shelling and area factor. The yield (t ha^{-1}) was calculated using the following formula: $GNY = FW^* \left(\frac{10}{EPA} * \frac{(100\text{-}\%M)}{86}\right) {}^*S$. Where: GNY is grain yield corrected to 14% moisture in t ha^{-1}; FW is the field weight; %M is the moisture percentage of the grain; (100-%M) is the coefficient of the percentage of dry matter; 86 is the correction coefficient of moisture at 14%; (10/EPA) is the correction factor to transform kg plot^{-1} into t ha^{-1}; EPA is the effective plot area, equal to 4.4 m^2, and S is the percentage of shelling, equivalent to 0.8.

Determination of anthocyanins

The content of anthocyanins in the bracts and cob of the varieties INIA-601, MM and Canteño was measured in four localities, randomly selecting ten plants per experimental unit following the methodology described by Jing and Giusti (2007); Gorriti *et al*. (2009), and it was characterized by the high-performance liquid chromatography (HPLC) chromatographic method. Samples of 0.3 g of cobs or 0.4 g of bracts, previously dried and ground, were used, placed in a beaker with 100 mL of the hydroacid composed of 850 ml of alcohol and 150 mL of 2% HCl, recording the total weight, it was placed in a magnetic stirrer at 60 °C for two hours at 300 rpm, covering the container with aluminum foil to prevent the evaporation of alcohol.

After weighing, the hydroacid was added until the initial weight was completed, leaving it to stand for 30 min. Five milliliters of sample were extracted and placed in a 100 ml flask, also calibrating with hydroacid and homogenizing, to then measure in a spectrophotometer at a wavelength of 535 nm. To obtain the concentration of anthocyanins equivalent to mg of cyanidin-3-glucoside/g dry weight, the following formula was used: total anthocyanins $\left(\frac{mg}{g}\right)=\frac{A \text{ x } MW \text{ x} DF\text{x}V}{\varepsilon \text{ x } l \text{ x } W}$. Where: A= is the absorbance read at a wavelength of 535 nm; MW= is the molecular weight of cyanidin-3-glucoside, 449.2 g mol^{-1}; DF= dilution factor; V= volume of the extraction solvent in ml; ε= molar extinction coefficient of 26 900; l= cell path length in cm; and W= sample weight in grams.

Data analysis

Data on yield, morphological and biometric variables and anthocyanins in both cob and bracts were analyzed by locality, calculating the means between the different experiments. The comparison of means was performed using the minimum significant differences (MSD at 0.05), using the InfoStat statistical program, version 2020 (Rienzo *et al*., 2013).

Results and discussion

Yield

Analyses of grain yield, plant and ear height are shown in Table 3 in the four sites evaluated, highly significant differences with $p \leq 0.001$ are observed for genotypes by environment. Table 4 shows the results of grain yield, it is observed that the best yield was obtained by the cultivar INIA-601, in Chala with 4.38 t ha^{-1}, in Tartar with 3.35 t ha^{-1}; however, in Shaullo, the cultivar MM reached 2.2 t ha^{-1}, a value similar to that obtained by INIA-601 with 2.1 t ha^{-1}. In Iglesiapampa, the cultivar MM stood out with 1.6 t ha^{-1}, also followed by the cultivar INIA-601, with 1 t ha^{-1}.

Table 3. Mean square (MS) of the interaction genotype by environment, *p*-value and coefficient of variation (CV) of yield, plant and ear height in three cultivars of purple corn in Cajamarca in the 2018-2019 cycle.

	Grain yield			Plant height			Ear height		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño	INIA-601	MM	Canteño
MS	8.52	3.4	2.17	152.2	0.58	0.19	0.41	0.44	0.17
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV	5.66	3.91	5.18	3.56	2.91	4.98	2.81	3.5	12.74

Table 4. Average values of grain yield, plant and ear height of three cultivars of purple corn grown in four localities in Cajamarca, Peru, 2018-2019 agricultural cycle.

Locality	Grain yield (t ha^{-1})			Plant height (m)			Ear height (m)		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño	INIA-601	MM	Canteño
Iglesiapampa	1 a	1.6 a	0.9 a	1.71 a	1.87 a	1.67 a	0.95 a	0.93 a	0.88 a
Tartar	3.4 c	2.2 b	2.6 d	2.77 d	2.7 c	2.12 c	1.6 c	1.58 d	1.3 b
Shaullo	2.1 b	2.2 b	1.6 b	1.87 b	1.95 a	1.86 b	0.92 a	0.85 a	0.89 a
Chala	4.4 d	3.8 c	1.9 c	2.14 c	2.32 b	2.12 c	1.03 b	1.25 c	1.13 b
MSD 0.05	0.32	0.2	0.2	0.16	0.14	0.2	0.07	0.08	0.28

Values followed by the same letter in a column are not significantly different at a significance level of 0.005.

It should be noted that the cultivar INIA-601 comes from a large population composed of 256 half-siblings, of which 108 come from the variety Morado de Caraz and 148 from Negro de Parubamba. This great genetic variability makes this cultivar very stable in the high Andean areas, whose altitudes range from 2 490 to 3 175 m (Pedraza *et al*., 2017). It is also known that the experimental cultivar called MM, follows in yield, since this cultivar is an improved synthetic cultivar that comes from INIA-601, while the cultivar Canteño obtained the lowest yield values in the four places of experimentation, probably because this cultivar has an adaptation area in the Lima region at altitudes between 1 800 to 2 500 m (Medina-Hoyos *et al*., 2020).

In a study conducted in 28 environments and using six cultivars in San Marcos, located in the Department of Cajamarca, yields of 2.77 t ha^{-1} in INIA-601, of 2.5 t ha^{-1} in MM and of 1.9 t ha^{-1} in Canteño were found. In the case of the varieties INIA-601 and MM, lower yield values than those found in the present research work were recorded in some places; while the cultivar Canteño registered a value very similar to that obtained in some tested places (Medina-Hoyos *et al*., 2020).

The results of plant height indicate that the cultivar MM was superior in all cases, except in Tartar. It is observed that, in Iglesiapampa and Shaullo, the values varied from 1.7 m to 1.95 m, that is, values lower than 2 m, while in Tartar and Chala, it was observed that plant heights were higher than 2 m, with INIA-601 standing out in Tartar with 2.77 m and in Chala, the cultivar MM with 2.32 m, in addition, in all cases the cultivar Canteño showed the lowest plant heights, from

1.67 to a maximum of 2.12 m. It should be noted that plant height is important to estimate or know this characteristic of each variety and they have the disadvantage that if they grow more than average they flake.

A correlation of the values of ear height with plant height is observed in the different varieties, the values obtained in the locality of Tartar were for INIA-601 (2.77 and 1.6 m), MM (2.7 and 1.58 M) and Canteño (2.12 and 1.3 m), followed by a lower plant and ear height in the locality of Chala, for INIA-601 (2.14 and 1.03 m), MM (2.32 and 1.25 m) and Canteño (2.12 and 1.13 m), respectively. On the other hand, it is also observed that, in the localities of Iglesiapampa and Shaullo, plant height values ranged from 1.6 to 2 m and ear height values ranged from 0.8 to 1 m.

The evaluated results of male and female flowering and root and stem lodging using the cultivars INIA-601, MM and Canteño show highly significant differences with $p \leq 0.001$ for genotypes by environment (Table 5). In Iglesiapampa, the variety MM was the earliest, it reached flowering (male and female) in the shortest time (Table 6) with 94.8 and 96.75 days, followed by the cultivar INIA-601 in Shaullo with 92.5 and 104 days, respectively. It should be noted that the three cultivars in Iglesiapampa, Tartar and Shaullo obtained small variations in both female and male flowering between 92.5 and 111.8 days; however, in Chala, the three cultivars had late flowering periods, their values varied between 143 to 155 days, but with a higher yield.

Table 5. Mean square (MS) of the interaction genotype by environment, *p*-value and coefficient of variation (CV) of female and male flowering and root and stem lodging in three cultivars of purple corn.

	Female flowering			Male flowering			Root lodging			Stem lodging		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño	INIA-601	MM	Canteño	INIA-601	MM	Canteño
MS	2458.6	2256.3	2000.4	2540.2	1852.4	1929.6	6.94	4.81	8.84	14.52	5.51	23.14
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV	1.69	1.46	1.29	1.51	0.66	2.36	6.02	6.14	10.62	9.05	3.29	13.66

Table 6. Average values of female and male flowering, root and stem lodging of the three cultivars of purple corn grown in four localities in Cajamarca, Peru, 2018-2019 cycle.

Locality	Female flowering (days)			Male flowering (days)			Root lodging (%)			Stem lodging (%)		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño	INIA-601	MM	Canteño	INIA-601	MM	Canteño
Iglesiapampa	102.5a	96.75a	103.3a	102b	94.8a	101.8a	0.71a	0.71a	0.71a	0.71a	1.84b	1.56b
Tartar	111.8b	113.3c	116.3c	112.3c	104.3b	105.5ab	3.73d	3.28d	4.08c	4b	3.26c	4.83c
Shaullo	104a	107.3b	111.5b	92.5a	103.5b	106.3b	1.28b	1.69c	1.31b	4.06b	3.99d	5.64d
Chala	155c	151.3d	153.8d	150d	143c	148.3c	1.61c	1.31b	1.54b	0.75a	1.52a	0.74a
MSD 0.05	3.28	3.59	3.28	3.62	1.55	5.73	0.23	0.22	0.43	0.45	0.18	0.91

The values of flowering days are important to know that the earlier the flowering, the lower its yield, compared to that variety whose flowering is late, as shown by the present research work, which shows a late flowering in the locality of Chala in the three varieties and the highest yield compared to the other localities, with the variety INIA-601 standing out with a female flowering of 155 days, male flowering of 150 days and with the highest yield of 4.4 t ha^{-1}. The lowest root lodging values occurred in Iglesiapampa using the three cultivars with the same statistical value of 0.71%, followed by those obtained in Shaullo and Chala with values in a range of 1.28-1.61%, while in Tartar, the highest values, from 3.28 to 4.08%, were obtained.

The stem lodging values had a similar pattern, the lowest values for the three cultivars occurred in Iglesiapampa, values similar to those obtained in Chala with a range of 0.71-1.52%, while in Tartar and Shaullo, higher values, from 3.26 to 5.64%, were obtained. As can be seen in the results, the locality of Tartar had the highest values of both root and stem lodging, since the soil probably had many nutrients and therefore the plant grew well above the average compared to the other three places and this caused it to fall.

It should be noted that there are two types of lodgings in purple corn, root lodging and stem lodging. Root lodging occurs when the stem falls more than 30 degrees from the vertical and stem lodging occurs when the stem breaks below the ear. Any type of lodging makes mechanical harvest difficult and leads to losses from 5 to 25% (García and Watson, 2003).

The evaluated results of proliferation and ear rot using the cultivars INIA-601, MM and Canteño show highly significant differences with $p \leq 0.001$ for genotypes by environment (Table 7). The prolificacy, which is the number of ears $plants^{-1}$ (Table 8), shows that if the value exceeds 1, it means that each plant has one or more ears, as is the case of INIA-601 in Shaullo, whose value is 1.3, which indicates that some plants have more than one ear, for the case of MM in the locality of Chala, it is 1.13 and for Canteño in Shaullo, it is 1.54, meaning that out of every three plants, two of them have two ears.

Table 7. Mean square of the interaction genotype by environment, *p*-value and coefficient of variation of the prolificacy and ear rot of three cultivars of purple corn.

	Prolificacy			Ear rot		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño
MS	0.08	0.09	0.6	23.26	1.18	105.2
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV	7.11	3.58	7.71	4.93	0.74	1.28

Table 8. Average values of prolificacy and ear rot of the three cultivars of purple corn in four localities in Cajamarca, Peru, 2018-2019 agricultural cycle.

Locality	Prolificacy			Ear rot (%)		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño
Iglesiapampa	1 a	0.77 a	0.72 a	11 c	10.2 c	16.6 c
Tartar	1.05 a	0.88 b	0.78 a	10.4 c	9.1 a	7.3 a
Shaullo	1.3 b	0.99 c	1.54 b	7.5 b	9.4 b	18.8 d
Chala	1.04 b	1.13 d	0.8 a	5.9 a	10.1 c	11.6 b
MSD 0.05	0.16	0.07	0.16	0.9	0.15	0.37

For the variety INIA-601, in all localities all plants had at least one ear; however, for the variety MM in the localities of Iglesiapampa, Tartar and Shaullo, there were plants that did not have ears and therefore the values are 0.77, 0.88 and 0.99, respectively, that is, the values are less than 1. The evaluation of ear rot shows that the cultivar INIA-601 obtained the lowest value with 5.9% in Chala, reaching up to 11% in Iglesiapampa. In the four places, the cultivar MM obtained statistically similar values, between 9.1 and 10.2%, while the cultivar Canteño obtained the highest rot values, reaching up to 18.8% in Shaullo.

This parameter is important in the agronomic study, since ear rot is generated by fungi, which not only reduces the quality of the product but also brings consequences to human and animal health, mainly due to the production of mycotoxins. This damage depends on the genotype, environmental factors such as the varied temperature in the crop cycle, soil moisture and relative humidity where the trial is carried out, in addition, the damage caused by birds is greater because it promotes the presence of fungi. Another aspect is the damage caused by the insect *Euxesta* sp., which attacks the ear from the formation of the pistils and continues during the development of the grain, producing a humid environment at the apex of the ear that facilitates the proliferation of fungi and therefore, ear rot (Medina-Hoyos *et al*., 2020).

The results show that the anthocyanin content evaluated in cob and bracts using the three cultivars INIA-601, MM and Canteño in four places shows highly significant differences with $p \leq 0.001$ for genotypes by environment (Table 9). Analyses of the anthocyanin content in cob were higher than the anthocyanin content in bracts, as can be seen in Table 10. The anthocyanin content in cob ranged from 4.6 to 7.9 mg g^{-1} of dry matter in the three cultivars and four places, with INIA-601 (7.9 mg g^{-1}), MM (7.2 mg g^{-1}) and Canteño (5.5 mg g^{-1}) standing out in Chala, followed by Shaullo, the value of INIA-601 was also 7.9 mg g^{-1}, followed by MM with 6.9 mg g^{-1} and Canteño with 5.4 mg g^{-1}.

Table 9. Mean square (MS) of the interaction genotype by environment, *p*-value and coefficient of variation (CV) of the amount of anthocyanins in the cob and bracts of the three cultivars of purple corn.

	Amount of anthocyanins in cob			Amount of anthocyanins in bracts		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño
MS	5.7	5.59	2.77	1.27	0.45	0.04
p-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
CV	2.37	3.47	2.61	2.88	4.02	28.03

Table 10. Average values of the amount of anthocyanins in the cob and bracts of three purple corn cultivars in four localities in Cajamarca, Peru, 2018-2019 agricultural cycle.

Locality	Amount of anthocyanins in cob (mg g^{-1})			Amount of anthocyanins in bracts (mg g^{-1})		
	INIA-601	MM	Canteño	INIA-601	MM	Canteño
Iglesiapampa	6.5 b	5.7 b	4.9 b	3.7 a	2.3 c	0.15 b
Tartar	5.5 a	4.6 a	3.7 a	3.9 b	1.7 a	0.06 a
Shaullo	7.9 c	6.9 c	5.4 c	4.9 d	1.6 a	0.24 c
Chala	7.9 c	7.2 c	5.53 c	4.5 c	2.1 b	0.03 a
MSD 0.05	0.35	0.44	0.27	0.26	0.16	0.07

In the anthocyanin content in bracts by genotype in the four places, there was little variation with significant differences between genotypes by environment, with the cultivar INIA-601 standing out with a range of 3.7-4.9 mg g^{-1}, MM varied from 1.6 to 2.3 mg g^{-1}, while the variety Canteño showed very small values of ≤0.2 mg g^{-1}. As shown, the highest values of the amount of anthocyanins in the cob and bracts were obtained in Chala in the three varieties, likewise, their grain yields were also the highest, with the variety INIA-601 standing out with a yield of 4.4 t ha^{-1}, amount of anthocyanins in cob of 7.9 mg g^{-1} and in bracts of 4.5 mg g^{-1}, with a good plant height of 2.14 m and ear height of 1.03 m, suggesting to be a potential variety for the import and export of purple corn.

Purple corn produces anthocyanins throughout the plant, especially in the cob and bracts, their values vary significantly (Fernandez-Aulis *et al*., 2019). The amount of anthocyanins depends on the extraction method, which must be validated, and on the factors involved such as solvent, temperature, pH, stirring time, solvent concentration and the mass-solvent ratio used in both classical and emerging technologies, until now there is no uniformity to obtain anthocyanins. If a cultivar has a good grain yield and a good amount and concentration of anthocyanins, it will generate profitable profits for the farmer.

It is known that for the cultivar INIA-601, it is estimated that for every 5 000 kg ha^{-1} of ear, 500 kg of cob and 200 kg of dried and chopped bracts can be produced, with an anthocyanin content of 6.12 and 3.18%, respectively, which is the way these products are marketed (Medina-Hoyos, 2020). The price of dried purple grain is \$2.00 kg^{-1} and the kg of cob or dried bracts is \$20.00 and therefore, in 700 kg of cob and dried and chopped bracts, an income of \$14 000.00 is generated. This means that producing 2 500 kg of grain at 14% moisture and 700 kg of cob and dried and chopped bracts in one hectare, the farmer could obtain a gross income of \$19 000.00. Subtracting the cost of production that approximates \$8 000.00 ha^{-1}, the net profit would reach \$11 000.00 ha^{-1} (MINAGRI, 2017).

As can be seen, maintaining fixed costs and selling the cob and bracts with a high concentration of anthocyanins and productivity, greater profitability would be obtained in the cultivars of purple corn. In a study published by Medina-Hoyos *et al*. (2020), using six cultivars in 28 locations in the Department of Cajamarca, province of San Marcos, the anthocyanin content in cob ranged from 4.66 to 6.12 mg g^{-1} and the anthocyanin content in bracts between 0.63 to 3.18 mg g^{-1}, values lower than those reported in the present research work. It should be noted that the amount of anthocyanins in the post-harvest stage decreases as the time of permanence of purple corn in the field increases, as reported by Medina-Hoyos *et al*. (2020), a factor that must be incorporated into the post-harvest protocols in order to obtain high economic results in the sowing of purple corn and its anthocyanin content in both cob and bracts.

Conclusions

The highest grain yield was obtained in Chala for the cultivars INIA-601 (4.38 t ha^{-1}) and for the synthetic improved purple cultivar MM (3.75 t ha^{-1}), in addition, both have high concentrations of anthocyanins expressed as cyanidin-3-glucoside in both the cob and the bracts, being for the cultivar INIA-601 (7.9 and 4.53 mg g^{-1}) and for MM (7.2 and 2.1 mg g^{-1}), respectively, considering both potential to increase the export and import of purple corn.

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