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SCIENTIFIC NOTE

'INIAP-Palmira 2014': a new drought-resistance barley variety

'INIAP-Palmira 2014': una nueva variedad de cebada con resistencia a la sequía

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ABSTRACT

Barley (*Hordeum vulgare* L.) is produced in the Ecuadorian highlands (> 3,000 m a.s.l.) primarily for self-consumption and small-scale commercialization. Not many crop species are adapted to this altitude; therefore, barley is one of a few crop species that can be grown at these locations. Severe environmental conditions can be found in the Ecuadorian highlands since the region is characterized by poor soils and water deficiency (< 300 mm year^{-1}). The Instituto Nacional de Investigaciones Agropecuarias (INIAP) has developed 'INIAP-Palmira 2014', a hulled two-row barley variety adapted to Ecuadorian agricultural conditions in the highlands. 'INIAP-Palmira 2014' showed acceptable yield performance as compared with the most popular improved barley cultivars in different production areas located in Ecuador. However, this new barley variety showed superior performance under water stress conditions in the highlands (>3,000 m a.s.l.). Additionally, 'INIAP-Palmira 2014' showed disease resistance, mainly to yellow rust, in all of the locations where the new variety was evaluated.

Key words: cereals, plant breeding, water stress, disease resistance, Ecuador.

RESUMEN

La cebada (*Hordeum vulgare* L.) es cultivada en la sierra ecuatoriana (> 3 000 msnm), principalmente, para el autoconsumo y para su comercialización a pequeña escala. No muchas especies de cultivos están adaptadas a esta altitud; por ello, la cebada es una de las pocas especies que pueden ser cultivadas en estos lugares. En la sierra ecuatoriana pueden encontrarse severas condiciones ambientales que se caracterizan principalmente por suelos pobres y escasez de agua con una precipitación anual inferior a 300 mm año^{-1}. El Instituto Nacional de Investigaciones Agropecuarias (INIAP) ha desarrollado la nueva variedad de cebada de dos hileras 'INIAP-Palmira 2014', la cual está adaptada a las condiciones de cultivo de los Andes de Ecuador. 'INIAP-Palmira 2014' mostró un rendimiento similar a las principales variedades mejoradas de cebada cultivadas en las diferentes áreas de producción cebadera de Ecuador. Sin embargo, mostró un rendimiento superior bajo condiciones de estrés hídrico en las tierras altas (>3.000 msnm). Adicionalmente, 'INIAP-Palmira 2014' mostró resistencia a las principales enfermedades de cebada, especialmente a roya amarilla, en todos los sitios donde fue evaluada.

Palabras clave: cereales, fitomejoramiento, estrés hídrico, resistencia a las enfermedades, Ecuador.

Introduction

Barley is one of the most important food crops in the Ecuadorian highlands (Fonte *et al*. 2012). In this region of Ecuador, farmers grow barley mostly for self-consumption; whereas, surplus grain is traded in the local markets. Barley constitutes a strategic crop in the agricultural system of the Andean region since it is adapted to altitudes over 3,000 m a.s.l. and not many crops are adapted to such altitudes (Ullrich, 2010). In Ecuador, more than 26,000 ha are cultivated with barley (FAO, 2013). One of the main problems in these production areas is the limited water resources and degraded soils, and most of the cereal production in the Andean highlands relies only on rainfall and a limited use of fertilizers (Barrera *et al*., 2012). The objective of the Wheat and Barley Breeding Program of the INIAP is to develop improved cultivars of cereals adapted to these environments with disease resistance and high yield. As a consequence, 'INIAP-Palmira 2014', a hulled two-row barley variety, has been released by the Instituto Nacional de Investigaciones Agropecuarias (INIAP). This new cultivar tolerates drought agricultural conditions. In addition, 'INIAP-Palmira 2014' has yellow rust (*Puccinia striiformis* f. sp. *hordei*) resistance, which is the main disease affecting barley in Ecuador. 'INIAP-Palmira 2014' was named after the Palmira parish located in the Chimborazo province of central Ecuador, which is one of the more important places for barley production. The Palmira parish is known as the desert of Palmira due to low precipitation (<300 mm year^{-1}) and sandy soils. Such conditions are ideal to select barley lines with drought resistance. However, 'INIAP-Palmira 2014' can

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be cultivated in any of the barley production areas of the Ecuadorian highlands.

Materials and methods

Pedigree and origin

'INIAP-Palmira 2014' was a breeding line developed by CIMMYT with the following pedigree: RHODES//TB-B/CHZO/3/GLORI-BAR/COPAL/4/ESC.II.72.83.3E.7E.5E.1E/5/ALELI. The developmental process was conducted in Mexico with the following selection history: CMB89A.915-A-1M-1Y-1B-0Y-0D-0AP. The pedigree breeding method was employed to develop the barley line. This method allows for the selection of superior individuals from the best families evaluated in early and late generations by keeping pedigree information. A detailed theory of this method can be found in Fehr (1987).

'lNlAP- Palmira 2014' was introduced to the Wheat and Barley Breeding Program of the INIAP in 2003. This new cultivar was part of an experimental nursery, which included 54 barley breeding lines selected in Mexico for drought resistance (Falconí *et al*., 2014).

Evaluation of adaptation, disease response and yield

'INIAP-Palmira 2014' was first evaluated in Saucer (Ecuador), during 2003 and 2004, along with the 54 barley lines that were part of a screening nursery sent by the ICARDA-CIMMYT Program. The evaluations were conducted under water stress conditions. The selected lines showed adaptation to these environmental conditions and disease resistance. During the next two cropping seasons (2005 and 2006), 'INIAP-Palmira 2014'was evaluated along with the previously selected barley lines and some controls at the Santa Catalina Research Station of the INIAP, near Quito, in the province of Pichincha. Santa Catalina has traditionally been considered as a hot spot for diverse strains of yellow rust (Dubin and Rajaram, 1996). A modified Cobb scale (0 – 100%) was used to assess the disease severity on the leaf surface (Gutiérrez *et al*., 2015; Peterson *et al*., 1948). In 2007, 2008, 2009, 2012, and 2013,'INIAP-Palmira 2014' was evaluated at the Santa Catalina Research Station and in farmers' fields for yield and disease resistance in 3.6 m^2 yield-plots with three replications per location. 'INIAP-Cañicapa 2003', one of the more popular and successful barley cultivars released through a farmer participatory research approach in Ecuador (Danial and Lindhout, 2006), was selected as the control to compare against 'INIAP-Palmira 2014'.

In 2010, a greenhouse experiment was conducted in the Chimborazo province to evaluate yield and agronomic traits, such as flowering and harvesting days. The plants were grown in 4 kg pots and the irrigation supply was controlled (100 and 200 mm).

Seed quality

The seed samples were analyzed for protein and fiber contents at the Nutrition and Quality Laboratory of the INIAP. Three samples that were randomly obtained from seed increase plots at the Santa Catalina Research Station were analyzed in 2013 using analytical methods described by Goering and Van Soest (1970) and Goering et al. (1972).

Statistical analysis

Analyses of variance for yield trials were conducted using Infostat v. 2010 (Di Rienzo *et al*., 2011). Yield, disease resistance, flowering and harvesting days, were tested for normality and subjected to an analysis of variance (ANOVA) using completely randomized design. Where the F-test was significant, a least significant difference (LSD) test was used at $P \leq 0.05$

Seed purification and increase

Every year, since 'INIAP-Palmira 2014' arrived to Ecuador, seed increase plots were grown at the Santa Catalina Research Station and this seed stock was employed for research purposes. Simultaneously, since 2008, 'INIAP-Palmira 2014' was increased in the Chimborazo province with farmers as part of participatory research projects.

Results

Agronomic and botanical description

'INIAP-Palmira 2014' has a short stature (0.9 - 1.1 m) and erect juvenile growth. It has compact spikes and the spike color at maturity is light yellow. Tiller number varies from 3-5. The plants possess lodging resistance. Flowering days range from 82.3 - 89.0 d, showing the earliest flowering time as compared with other cultivars (Tabs. 1 and 2). Barley cultivars with a flowering time of around 80 - 90 d after planting when grown under equatorial environments and moderate temperature (~15°C) can be considered as early-flowering genotypes (Gallagher and Soliman, 1988).

Yield performance

The yield average of 'INIAP-Palmira 2014' was 3.5 t ha^{-1} in 2005, 5.2 t ha^{-1} in 2006 and 4.1 t ha^{-1} in 2007. The yield registered in these evaluations was higher than 'INIAP-Cañicapa 2003', which showed a yield average of 3.0 t ha^{-1} in 2005, 5.1 t ha^{-1} in 2006, and 3.7 t ha^{-1} in 2007; however, no significant differences were detected. Eventually, 'INIAP-Palmira 2014' was evaluated in yield trials with replicates in four and six locations in the Chimborazo province in 2008 and 2009, respectively (Tabs. 1 and 2).

In most of the evaluations, 'INIAP-Palmira 2014' was statistically similar to 'INIAP-Cañicapa 2003' ($P \leq 0.05$). The yields observed in the experimental station and production fields were superior to the yields of commercial production in the Ecuadorian highlands (Bossio and Cassman, 1991; FAO, 2013). The greenhouse experiments for the water deficit response demonstrated that 'INIAP-Palmira 2014' was superior to 'INIAP-Cañicapa 2003'. In these experiments, the yield of 'INIAP-Palmira 2014' was up to six times higher than that of 'INIAP-Cañicapa 2003' (Tab. 3).

TABLE 1. Agronomic traits and *Puccinia striiformis* severity in barley cultivars and advanced lines in four locations in the Chimborazo province (Ecuador) for 2008.

Accession name	Yield (t ha^{-1})	*Puccinia striiformis*		Flowering days
		Leaf (cm^2/plant)	Spike (%)	
'INIAP-Palmira 2014'	1.7	4.0	4.0	82.3
'INIAP-Cañicapa 2003'	1.3	13.0	5.7	98.0
GAL/PI6384//ESC.II.72.607.1E.4E.5E/5/DC-B/…	1.2	28.3	9.0	88.0
'Franciscana'	1.1	7.7	5.0	91.0
'INIAP-Atahualpa 92'	1.1	35.3	5.7	95.0
'Rita Pelada'	0.7	19.0	3.0	91.0
AKRASH//WI2291/WI2269/3/SLS/AKRASH	0.5	65.0	29.0	88.0
Mean	1.1	24.4	8.7	90.4
LSD (0.05)[1]	0.4	10.8	7.0	4.7
CV, %	37.5	25.7	41.2	3.7

[1] Values that differ by an amount less than or equal to the LSD should be considered the same.

TABLE 2. Agronomic traits and *Puccinia striiformis* severity in barley cultivars and advanced lines in six locations in the Chimborazo province (Ecuador) for 2009.

Accession name	Yield (t ha^{-1})	*Puccinia striiformis*		Flowering days
		Leaf (cm^2/plant)	Spike (%)	
'INIAP-Palmira 2014'	1.0	0.7	0.3	89.0
'INIAP-Cañicapa 2003'	1.2	3.7	0.8	110.0
'INIAP-Pacha 2003'	1.1	7.8	0.3	96.0
'Franciscana'	0.9	2.1	0.3	95.0
GAL/PI6384//ESC.II.72.607.1E.4E.5E/5/DC-B/…	0.8	6.1	0.5	99.0
TOCTE/3/GAL/PI6384//ESC.II.72.607.1E.4E.5E/4/BOLDO/MJA	1.0	0.1	0.2	99.0
TOCTE/3/GAL/PI6384// ESC.II.72.607.1E.4E.5E/4/BOLDO/MJA	0.9	17.0	3.3	99.0
Mean	1.01	0.51	0.51	98.2
LSD (0.05)[1]	0.38	0.13	0.06	3.8
CV, %	37.6	38.1	17.9	5.8

[1] Values that differ by an amount less than or equal to the LSD should be considered the same.

TABLE 3. Yield, spike length, harvesting days, and flowering days of six cultivars/advanced lines in the greenhouse evaluated under different irrigation rates in the Chimborazo province (Ecuador) for 2010.

Accession name	Yield (g/plant)	Spike length (cm)	Harvesting days	Flowering days
'INIAP-Palmira 2014'	19.3	2.6	110.6	82.8
GAL/PI6384//ESC.II.72.607.1E.4E.5E/5/DC-B/…	15.9	2.4	119.4	85.0
'INIAP-Pacha 2003'	20.2	2.7	120.0	83.4
TOCTE/3/GAL/PI6384// ESC.II.72.607.1E.4E.5E/4/BOLDO/MJA	10.7	1.9	121.9	87.1
TOCTE/3/GAL/PI6384//ESC.II.72.607.1E.4E.5E/4/BOLDO/MJA	5.8	2.6	122.5	94.0
'Franciscana'	2.4	2.7	121.3	99.0
'INIAPCañicapa2003'	3.0	2.0	125.0	100.0
Mean	11.0	2.4	120.1	90.2
LSD (0.05)[1]	5.0	0.6	4.2	6.5
CV, %	19.4	14.0	2.19	4.6

[1]Values that differ by an amount less than or equal to the LSD should be considered the same.

In seed production plots planted during 2008, 2009, 2011, and 2012 in three provinces, 'INIAP-Palmira 2014' produced more than 'INIAP-Cañicapa 2003' (Tab. 4).

TABLE 4. Seed production in commercial plots of 'INIAP-Palmira 2014' versus 'INIAP-Cañicapa 2003' over four years in three locations of the Ecuadorian highlands.

Year	Province	Location	Yield (t ha^{-1}) 'INIAP-Palmira 2014'	'INIAP-Cañicapa 2003'
2008	Chimborazo	BaldaLupaxi	2.2	1.8
2009	Chimborazo	BaldaLupaxi	2.1	1.8
2011	Pichincha	EESC	3.1	2.6
2012	Imbabura	Otavalo	2.3	2.1
Mean	2.2	1.8		

Seed traits and composition

'INIAP-Palmira 2014' was approximately 40 g for 1,000 kernels. The average was obtained from the replicated yield trials. The protein and fiber contents of three samples were 12.1% and 5.6%, respectively.

Disease resistance

In 2003 and 2004, 'INIAP-Palmira 2014' was evaluated in screening nurseries for disease response in Saucer, Loja Province, showing high levels of resistance to yellow rust. In 2005 and 2006, 'INIAP-Palmira 2014' was evaluated at the Santa Catalina Research Station in yield trials, where yellow rust pressure is high and stable over time (Xi *et al.*, 2013) . In these evaluations, 'INIAP-Palmira 2014' continued showing yellow rust and BYDV resistance; however, the severity for leaf rust reached 60% in Santa Catalina in 2005. In the following years (2007-2013), the evaluations of 'INIAP-Palmira 2014' continued for yield and disease response. In the Pichincha and Chimborazo provinces, 'INIAP-Palmira 2014' showed resistance to yellow rust and BYDV. The leaf rust evaluations showed a weakness in the resistance of 'INIAP-Palmira 2014' only at the Santa Catalina Research Station. Symptoms of leaf rust were not registered in the other locations. Moreover, the evaluations conducted in the Chimborazo province during 2008 and 2009 in four and six locations, respectively, showed that 'INIAP-Palmira 2014' held the highest level of yellow rust resistance among the evaluated barley genotypes (Tabs. 1 and 2).

Availability

The Department of Seed Production and the Wheat and Barley Breeding Program of the INIAP will supply seeds for commercial seed production and research. Farmer associations located in Palmira are currently producing artisan seeds to distribute in the local production areas.

Conclusions

'INIAP-Palmira 2014' is adapted to the Ecuadorian highlands, which are characterized as having water deficiency. This new barley variety is able to reach acceptable yield under these conditions. One special characteristic seen in 'INIAP-Palmira 2014' is high levels of disease resistance, especially to yellow rust, which is the most common and destructive disease for barley production in Ecuador. Currently, small-scale farmers in Ecuador have another barley variety that was developed by the INIAP with better characteristics for food production.

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