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Research article

New wheat variety INIA 440 - K'ANCHAREQ: Selection and agronomic and commercial characterization in Cusco, Peru

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A R T I C L E I N F O

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A B S T R A C T

The objective of this study was to select and characterize agronomically the advanced bread wheat line H - 1246 which gave origin to the INIA wheat variety 440 - K'ANCHAREQ. The research included yield trials in farmers' fields during 4 production seasons (2012–2016), adaptation and agronomic efficiency trials in two production seasons (2016–2018). In addition, the reaction to Yellow Rust and distinctness, uniformity and stability characteristics of the new wheat variety and commercial controls were evaluated. The plots for each of the trials were conducted under a Completely Randomized Block design with three replications. At the end of the trials, desirable characteristics in the baking industry such as hectoliter weight, protein, ash, gluten and flour moisture were evaluated. The results showed that the new INIA 440 - K'ANCHAREQ variety has ten clear differences in qualitative characteristics, which distinguish it from other varieties and remained constant during the trials. The yield trials between locations showed the adaptation of the INIA 440 - K'ANCHAREQ variety to the different locations due to its high yield and hectoliter weight values. At the locality level, Andenes obtained the highest values in most of the production seasons. Adaptation trials during the second season showed the superiority of the new INIA 440 - K'ANCHAREQ variety for variables such as yield, plant height, ear size and thousand grain weight. The new variety showed no signs of stripe rust during the trials. Industrial quality trials indicated that it has good characteristics for the baking industry.

1. Introduction

Globally, flour wheat (*Triticum aestivum* L.) has the largest planted area [1]. According to projections of the United States Department of Agriculture report that world wheat production during the 2021/22 commercial cycle would reach a historic figure of 776 million tons, this new record is propitiated by the annual increase of 1.1% in the harvested area, with the main wheat producers being the European Union, India and China, with 18, 17.6 and 14.1% of participation respectively, where China is also the main

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consumer with 149 million tons [2].

Wheat is a crop of economic importance due to its relevant nutritional composition such as: protein, lipid, fiber, minerals (iron, magnesium, zinc, potassium, calcium and phosphorus), in addition to containing amino acids [3]. Efforts to meet the demand for wheat in Peru have allowed research in genetic improvement to focus on optimizing yield, production, grain quality and resistance to biotic factors in order to provide flour wheat crop alternatives with promising characteristics, especially for the baking industry [4].

Likewise, the advantage of adapting to adverse climate conditions in different agroecological zones allows wheat cultivation to be considered as a profitable alternative compared to other crops [5]. In 2019 and 2020, Peru imported 1.87 and 2.11 million tons. of wheat, respectively; while domestic production in the August 2019 to July 2020 season reached 187,000 tons, which barely represented 8% of consumption in the country [6].

Wheat stripe rust (*Puccinia striiformis*) is one of the most severe diseases worldwide and is present in all regions where this crop is produced in the world, genetic resistance in varieties is the most effective strategy for the control of this disease, currently there are wheat genotypes that have resistance in different years and production environments [7]. Yellow rust not only causes grain yield losses, but also significantly reduces the hectoliter weight; the evolution of this disease over time will depend on the genetic behavior of the cultivar and the application of foliar fungicide [8].

Studies such as those of Córdova and Solís [9] conducted the agronomic evaluation of the response of four promising durum wheat (*Triticum durum*) lines to nitrogen fertilization in two locations in the province of Bolívar, obtaining as a result that the germplasm meets the nutritional quality indicators demanded by the flour industry, also showing its great potential for territories located between 2200 and 2850 m above sea level, contributing to food security.

According to Flores-Margez et al. [10]; with the availability of new wheat varieties, it is necessary to update the information on the agronomic response of this new variety in relation to agroclimatic conditions in order to provide alternatives for higher yields and grain quality. In Peru, through the National Institute for Agrarian Innovation (INIA), the genetic improvement of cereals, including wheat, has been studied for several years. In addition, to improve the quality of wheat production and optimize resistance to Yellow Rust, the National Cereal, Andean Grains and Legumes Program of the Andenes - Cusco Agricultural Experiment Station of the National Institute for Agrarian Innovation - INIA, uses the standardized planning process for the development of technologies in wheat and barley, which has been studied for several years [11]. To this end, the development of new varieties should contribute to the selection of genotypes superior to local varieties in their sanitary, yield and baking quality characteristics that will allow producers to adopt technology, contributing to the productive increase of flour wheat for the market with new varieties. In this context, the objective of this study was to select and characterize agronomically the advanced bread wheat line H - 1246 which gave origin to the INIA wheat variety 440 - K'ANCHAREQ.

2. Materials and methods

2.1. Preliminary identification trials

There were 126 wheat lines from the CIMMYT nursery with which evaluations were carried out in the nursery with respect to heading, plant height, thousand grain weight, hectoliter weight, yield and health. Once this genetic material selection work was

Table 1
Location of experiments for yield, adaptation and efficiency trials.

Year	Location	Altitude	Latitude (S)	Longitude (W)	District	Province	Region
2010	Andenes	3418	13°26′19.3″	72°14′11.1″	Zurite	Anta	Cusco
2011	Andenes	3418	13°26′19.3″	72°14′11.1″	Zurite	Anta	Cusco
2012	Andenes	3418	13°26′19.3″	72°14′11.1″	Zurite	Anta	Cusco
2013	Andenes	3437	13°26′	72°14′	Zurite	Anta	Cusco
2013	Phiry	2900	13°37′	72°08′	Ollantaytambo	Urubamba	Cusco
2014	Andenes	3437	13°26′	72°14′	Zurite	Anta	Cusco
2014	Phiry	2900	13°37′	72°08′	Ollantaytambo	Urubamba	Cusco
2014	Mollepata	2976	13°30′44″	72°31′58″	Mollepata	Anta	Cusco
2015	Andenes	3437	13°26′	72°14′	Zurite	Anta	Cusco
2015	Chilca	2750	13°37′	72°08′	Ollantaytambo	Urubamba	Cusco
2016	Andenes	3437	13°26′	72°14′	Zurite	Anta	Cusco
2016	Maras	3230	13°19′18.8″	72°09′42″	Maras	Urubamba	Cusco
2016	Occoruro	3162	13°32′29.50″	72°44′48.45″	Curahuasi	Abancay	Apurímac
2017	Andenes	3404	13°26′35.18″	72°14′24.34″	Zurite	Anta	Cusco
2017	Huanoquite	3514	13°41′11.63″	72°1′2.42″	Huanoquite	Paruro	Cusco
2017	Occoruro	3220	13°32′29.50″	72°44′48.45″	Curahuasi	Abancay	Apurímac
2017	Andenes	3404	13°26′35.18″	72°14′24.34″	Zurite	Anta	Cusco
2017	Huanoquite	3514	13°41′11.63″	72°1′2.42″	Huanoquite	Paruro	Cusco
2017	Occoruro	3220	13°32′29.50″	72°44′48.45″	Curahuasi	Abancay	Apurímac
2018	Andenes	3404	13°26′ 35.18″	72°14′24.34″	Zurite	Anta	Cusco
2018	Huanoquite	3275	13°40′18.65″	71°52′2.06″	Huanoquite	Paruro	Cusco
2018	Maras	3469	13°20′23.314″	72°9′50.448″	Maras	Urubamba	Cusco
2018	Chilca	2779	13°14′50″S	72°17′31″	Ollantaytambo	Urubamba	Cusco

completed and in accordance with the protocols for the generation of new wheat varieties [11], it was decided to work with the H-1246 line for subsequent research trials.

2.2. Farmers' field yield trials

These were installed in six locations between the years 2012–2016, evaluating 4 productive campaigns (Table 1).

For the trials in the different locations between the years 2012–2016, INIA 405 San Isidro and INIA 419 San Francisco varieties were used as controls, considering that they are the main commercial varieties grown by producers in the study area and are accepted in the baking industry. However, they currently show a decrease in production and productivity due to their susceptibility to adverse biotic factors.

For the Distinguishability, Uniformity and Stability trials, two agricultural campaigns 2016–2017 and 2017–2018 were considered, for the 2016–2017 campaign three locations were considered and for the 2017–2018 campaign four locations were considered (Table 1). In both campaigns, the local commercial variety INIA 419 San Francisco was considered as a control.

2.3. Planting seasons

This was a function of the zone and altitudinal level. In the locality of Andenes in November, Ollantaytambo, Huanoquite and Curahuasi in December and in the locality of Urubamba between November and December.

2.4. Genetic material

The International Maize and Wheat Improvement Center (CIMMYT) and the Global Research Partnership for a Food Secure Future are the entities responsible for generating maize and wheat germplasm that are shared as a public product; also research entities such as INIA (National Institute for Agrarian Innovation) through the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) have access to wheat genetic material in the process of pre-improvement for use in the improvement and development of new varieties and contribute to solving production problems, among others. Within the framework of TIRFAA for the development of the new variety, genetic material from CIMMYT was used from the international nursery for semi-arid zones introduced to Peru with 126 lines in the 2009–2010 agricultural season, including the ATTILA/3/URES/PRL//BAV92/4/WBLL1 line, whose pedigree is, CMSA01M00244 T-040Y–040P0M-030 ZTM-040SY-040M-3Y-0M, coded for the registration of field evaluations with H-1246 which gave rise to the INIA wheat variety 440 - K'ANCHAREQ.

2.5. Design and management of experimental plots

The experimental design of Randomized Complete Blocks with three replications (DBCA) was applied for both trials. The experimental plots in Cycle 1 for the trials at EEA Andenes were 600 m^2 and 900 m^2 in farmers' fields.

In the second cycle, adaptation and efficiency trials were carried out during the 2016–2017 and 2017–2018 growing seasons in farmers' fields compared with a local variety INIA 419 San Francisco, with plots of 600 m^2 at EEA Andenes and 1800 m^2 in farmers' fields.

In cycle 1, we worked with 10 treatments (varieties and lines) H-1246, H-1201, H-1208, H-1222, H-1228, H-1242, H-1245, H-1254, T1 = INIA 405 San Isidro and T2 = INIA - 419 San Francisco and for cycle 2 we worked with three treatments (varieties and lines) H-1246 (INIA 440 K'ANCHAREQ), H-1254 and INIA 419 San Francisco.

For the identification trials carried out at EEA Andenes and in farmers' fields, the same inputs and management were used as required within the participatory research approach. Soil preparation generally consisted of plowing, harrowing and furrowing with agricultural machinery at EEA Andenes and only plowing and harrowing in the farmers' field.

The planting density for the preliminary and uniform yield stages was carried out in furrow system using 120 kg ha^{-1} of seed and for the experiments conducted in farmers' fields the system was broadcast sowing with 180 kg ha^{-1} of seed and the covering was carried out with agricultural machinery. The fertilization level used was 80–80-00 of N, P2O5, K2O, agricultural Urea was used as a source of nitrogen and Ammonium Phosphate was used for phosphorus, the latter being applied in its totality at the time of sowing and the nitrogen supplement at the tillering stage.

For the control of broadleaf weeds, the herbicide Metsulfuron methyl (Ally) was used at a dose of 10 g/200 l of water supplemented with agricultural adherent applied between 30 and 45 days after planting, followed by the manual elimination of weeds of narrow-leaved species such as *Avena fatua*, *Bromus catharticus* Vahl, among others.

The wheat grain harvest was semi-mechanized (manual cutting of the central furrows of each treatment evaluated, and in the case of farmers' fields in the central areas of each plot, threshing with stationary machines) and grain cleaning with experimental aerators.

2.6. Evaluation variables

The evaluations were carried out through the guidelines for the execution of the UPOV TG/3/12 examination, for the determination of the yield components, reaction to diseases and Distinctness, Uniformity and Stability (DUS) characteristics and the INIA variety generation protocol [11] prioritizing the variables associated with yield components, phenology based on the decimal scale of Zadoks et al. [12]; health through infection coefficients based on the host response to infection in the field (Degrees of rust severity

Fig. 1. Evaluation of wheat rust in the field.

according to the modified Cobb scale, according to Peterson et al. [13]; the most distinguishable, homogeneous, stable characteristics of the variety and the bromatological and processing characteristics at the grain level correspond to hectoliter weight, thousand grain weight and chemical analysis of proteins, ashes, gluten and moisture in flour, in order to determine baking quality.

The evaluations of reaction to *Puccinia striiformis* Westend f. sp. tritici (yellow rust) were carried out according to the methodology of Roelfs et al. (1992) who took into account four methodologies, taking into consideration the development phases of the Zadoks scale, the guide for disease identification proposed by Prescott and the modified Cobb scale, which is based on visual observations with the use of intervals of the following percentages: 5, 10, 20, 40, 60, and 100%, determining the severity and field response referred to the type of infection classified and the combination of data on disease severity and host response in a single value called Coefficient of Infection (C. I.) according to the scale given by Roelfs et al. (1992). Field rust severity response readings were recorded at three time points with 15-day periods to determine the area under the disease growth curve (AUDPC) and the response of the treatments under study to infection in the field (Fig. 1).

The registration of commercial wheat cultivars Law No. 27262 and its specific regulation MINAGRI 2008, indicate that they must be executed at least in three locations and in two consecutive seasons compared with at least one control chosen among the cultivars of the same species registered in the register of commercial cultivars. With this purpose to develop adaptation and efficiency trials that allow the technical and economic validation of the wheat variety INIA 440 K'ANCHAREQ (H-1246) these trials were executed in the 2016–2017 and 2017–2018 agricultural campaigns using as a comparison control the INIA 419 San Francisco variety registered in the cultivar registry and of use by producers in the study area.

2.7. Data analysis

In this phase, exploratory analyses were performed to test the assumptions of normality and homogeneity of variance, summary measures were calculated, analysis of variance, Duncan's multiple comparison at 5% significance. For this, the statistical software InfoStat version 2018p was used.

3. Results

3.1. Distinctness, homogeneity and stability characteristics of INIA 440 K'ANCHAREQ wheat

Table 2 shows the ten clear differences in the qualitative characteristics of the new variety INIA 440 K'ANCHAREQ, compared to the commercial varieties INIA 419 San Francisco and INIA 405 San Isidro, during the two evaluation cycles, which allow visualizing the characteristic expression that makes it different, showing homogeneity and stability during the two evaluation cycles.

3.2. Yield components of wheat varieties in farmers' field (2012–2016)

3.2.1. Yield of wheat varieties (t ha^{-1})

The analysis of variance for yield in the four consecutive seasons showed significant differences at the level of locations and varieties. For the 2012, 2013 and 2015 campaigns, the highest yield averages were obtained by the Andenes locality with the INIA 440 KANCHAREQ variety with averages of 9.87, 8.87 and 7.55 t ha^{-1}. The lowest average for the 2012 to 2013 campaign was the Phiry locality with the INIA 405 San Isidro variety (4.35 t ha^{-1}). In the 2013 to 2014 campaign the lowest average was reported with the Mollepata locality for variety INIA 419 San Francisco with 2.45 t ha^{-1}. In the 2014 to 2015 campaign the lowest average was reported with the Andenes locality with variety INIA 419 San Francisco with 2.99 t ha^{-1} and for the 2015 to 2016 campaign the lowest average was reported with the Maras locality and variety INIA 405 San Isidro with 1.09 t ha^{-1} (Table 3).

Table 2
Distinctness, uniformity and stability characteristics of INIA 440 K'ANCHAREQ and commercial varieties.

Characteristics UPOV TG/3/12	INIA 440 K'ANCHAREQ	INIA 419 San Francisco	INIA 405 San Isidro
Plant: Frequency of plants with recurved flags	Low	Medium	Medium
Pennant: sheath glauescence	Strong	Medium	Medium
Banner: limb glaucoscence	Strong	Medium	Medium
Spike: glauescence	Strong	Medium	Medium
Stem: glaucosity of the spike neck	Strong	Weak	Weak
Herringbone: shape profile view	Pyramidal	Parallel edges	Parallel edges
Apical segment of the rachis: surface of the convex surface hairs.	None or very little	Small	Small
Lower glume: shoulder width	Narrow	Very wide	Very wide
Lower glume: shoulder shape	Narrow	Medium	Medium
Lower glume: Beak shape	Moderately curved	Slightly curved	Slightly curved

Table 3
Yield by localities and varieties, 2012–2016.

Campaign/Locality	INIA 440 K'ANCHAREQ ($\bar{x}$±DE)	INIA 419 San Francisco ($\bar{x}$±DE)	INIA 405 San Isidro ($\bar{x}$±DE)
2012–2013			
Andenes	9.87 ± 0.93 a	8.94 ± 0.81 ab	8.75 ± 0.4 ab
Phiry	5.22 ± 0.93 a	4.68 ± 0.42 ab	4.35 ± 2.6 ab
Media	**7.54**	**6.81**	**6.55**
2013–2014			
Andenes	8.87 ± 0.6 a	7.16 ± 1.28 ab	4.41 ± 0.71 c
Phiry	3.97 ± 0.43 a	4.33 ± 1.01 ab	3.92 ± 0.57 a
Mollepata	2.74 ± 1.45 ab	2.45 ± 0.82 ab	3.07 ± 1.55 ab
Media	**5.19**	**4.65**	**3.80**
2014–2015			
Andenes	3.45 ± 0.33 bc	2.99 ± 0.51 c	3.39 ± 0.14 d
Phiry	5.19 ± 0.88 ab	5.69 ± 0.37 a	3.75 ± 0.5 c
Media	**4.32**	**4.34**	**3.57**
2015–2016			
Andenes	7.55 ± 2.01	6.59 ± 0.42 a	6.46 ± 1.42 a
Occoruro	2.19 ± 0.57	2.03 ± 0.46 a	2.09 ± 0.99 a
Maras	1.34 ± 1.34	1.72 ± 0.47 ab	1.09 ± 0.46 b
Media	**3.69**	**3.45**	**3.21**

$\bar{x}$ = average, SD = standard deviation. Varieties with the same letter are not significantly different according to Duncan's multiple comparison at 5% probability.

3.3. Thousand grain weight (g) of wheat varieties (2012–2015)

The analysis of variance showed significant statistical differences for locations and varieties. For the 2012–2013 season, the Andenes locality with the INIA 419 San Francisco variety reported the highest average for the thousand grain weight variable at 51.53 g. For the 2013–2014 and 2014–2015 campaigns the highest averages were reported by the Phiry locality and the INIA 440 K'ANCHAREQ variety with 61.07 and 52.67 g respectively.

The lowest average in the 2012–2013 campaign was observed in the Phiry locality with the INIA 405 San Isidro variety with 31.47 g, in the 2013–2014 and 2014–2015 campaigns the lowest averages were reported in the Andenes locality with the INIA 405 San Isidro variety with 41.10 and 37.93 g (Table 4).

3.4. Trial weight (kg hl^{-1}) of wheat varieties (2012–2016)

Regarding the hectoliter weight, the analysis of variance showed significant differences at the level of locations and varieties. For the 2012 to 2013 campaign the highest average was obtained in the Andenes locality with the INIA 405 San Isidro variety with 81.47 kg hl^{-1} and the lowest average in the Phiry locality with the INIA 440 K'ANCHAREQ variety with 52.40 kg hl^{-1}. In the 2013–2014 campaign the highest value was presented in the Phiry locality with the variety INIA 419 San Francisco with 80.93 kg hl^{-1} and the lowest average in the Andenes locality with the variety INIA 405 San Isidro with 74.80 kg hl^{-1}. For the 2014–2015 season, the highest average was in the Phiry locality with the INIA 419 San Francisco variety (79.80 kg hl^{-1}) and the lowest average was in the Andenes locality with the INIA 405 San Isidro variety (73.53 kg hl^{-1}). For the 2015–2016 season the highest average was obtained in the Andenes locality with variety INIA 419 San Francisco (79.33 kg hl^{-1}) and the lowest average was reported in the Maras locality with variety INIA 405 San Isidro (71.03 kg hl^{-1}) Table 5.

Tabla 4
Peso de mil granos (g), 2012–2015.

Campaign/Locality	INIA 440 K'ANCHAREQ (x̄±DE)	INIA 419 San Francisco (x̄±DE)	INIA 405 San Isidro (x̄±DE)
2012–2013			
Andenes	47.53 ± 1.51 b	51.53 ± 10.97 ab	47.47 ± 2.57 b
Phiry	36.27 ± 31.41 a	35.27 ± 30.54 ab	31.47 ± 31.41 a
Media	**41.90**	**43.40**	**39.47**
2013–2014			
Andenes	50.73 ± 1.62 bc	50.87 ± 1.96 bc	41.10 ± 2.75 d
Phiry	61.07 ± 0.59 ab	55.30 ± 1.14 bcd	45.23 ± 0.92 d
Mollepata	49.67 ± 2.16 ab	45.93 ± 0.61 ab	41.67 ± 1.03 ab
Media	**53.82**	**46.83**	**43.17**
2014–2015			
Andenes	46.67 ± 0.70 cd	44.73 ± 0.64 cd	37.93 ± 0.90e
Phiry	52.67 ± 0.58 a	48.93 ± 0.90 a	48.40 ± 9.70 a
Media	**49.67**	**46.83**	**43.17**

x̄ = average, SD = standard deviation. Varieties with the same letter are not significantly different according to Duncan's multiple comparison at 5% probability.

Table 5
Hectoliter weight (kg hl^{-1}), 2012–2016.

Campaign/Locality	INIA 440 K'ANCHAREQ (x̄±DE)	INIA 419 San Francisco (x̄±DE)	INIA 405 San Isidro (x̄±DE)
2012–2013			
Andenes	80.53 ± 0.61 a	79.47 ± 1.51 ab	81.47 ± 1.01 a
Phiry	52.40 ± 0.38 a	53.60 ± 1.42 ab	52.80 ± 0.73 a
Media	**66.47**	**66.54**	**67.14**
2013–2014			
Andenes	78.27 ± 1.29 ab	79.33 ± 1.62 a	74.80 ± 0.80 bc
Phiry	80.67 ± 0.46 ab	80.93 ± 2.20 ab	79.73 ± 1.89 ab
Mollepata	78.53 ± 0.61 a	78.67 ± 0.92 a	78.80 ± 0.80 a
Media	**79.60**	**79.64**	**77.78**
2014–2015			
Andenes	77.47 ± 0.23 cd	78.80 ± 0.80 b	73.53 ± 0.76 b
Phiry	78.40 ± 0.69 a	79.80 ± 0.20 a	79.6 ± 0.69 a
Media	**77.94**	**79.30**	**76.57**
2015–2016			
Andenes	75.33 ± 1.22 bc	79.33 ± 0.61 a	74.73 ± 3.97 cd
Occoruro	78.53 ± 1.01 ab	78.93 ± 0.23 ab	78.67 ± 1.85 ab
Maras	74.13 ± 1.62 ab	72.93 ± 1.62 ab	71.03 ± 7.35 b
Media	**76.00**	**77.06**	**74.81**

x̄ = average, SD = standard deviation. Varieties with the same letter are not significantly different according to Duncan's multiple comparison at 5% probability.

3.5. Adaptation and efficiency of agronomic variables of wheat varieties

3.5.1. Yield (t ha^{-1})

For the 2016–2017 campaign, significant differences were observed between localities for each variety, the highest value was recorded for the Andenes locality and the variety INIA 419 San Francisco (10.45 t ha^{-1}) and the lowest value was reported in the Occoruro locality for the same variety (2.03 t ha^{-1}). In the 2017–2018 season, the highest value was recorded in the Andenes locality with the INIA 440 K'ANCHAREQ variety (6.4 t ha^{-1}) and the lowest value in the Chilca locality with the INIA 419 San Francisco variety (1.98 t ha^{-1}) (Table 6).

3.5.2. Thousand grain weight (g)

For the 2016–2017 campaign the highest value was recorded with INIA 440 K'ANCHAREQ in the Occoruro locality (50.67 g) and the lowest with INIA 419 San Francisco in the Huanoquite locality (49.20 g). In the 2017–2018 season the INIA 440 K'ANCHAREQ variety in the Huanoquite locality obtained the highest average with 57.63 g and the INIA 419 San Francisco variety in the Andenes locality the lowest value with 44.90 g (Table 6).

3.5.3. Hectoliter weight (kg hl^{-1})

During the 2016–2017 campaign the highest averages were reported with the variety INIA 419 San Francisco in the Andenes and Occoruro localities with 78.93 kg hl^{-1} and the lowest average with the variety INIA 440 KÁNCHAREQ in the Andenes locality with 76.40 kg hl^{-1}. For the 2017–2018 season the highest average with the INIA 419 San Francisco variety in the Maras locality with 80.40

Table 6
Agronomic variables of wheat varieties, 2016–2018.

Campaign/ Locality	Yield (t ha^{-1})		Thousand grain weight (g)	
	INIA 440 K'ANCHAREQ ($\bar{x}$±DE)	INIA 419 San Francisco ($\bar{x}$±DE)	INIA 440 K'ANCHAREQ ($\bar{x}$±DE)	INIA 419 San Francisco ($\bar{x}$±DE)
2016–2017				
Huanoquite	4.83 ± 0.04 a	4.65 ± 1.70 a	50.00 ± 2.12 a	49.20 ± 2.26 a
Andenes	8.52 ± 0.03 b	10.45 ± 0.91 a	50.17 ± 2.63 b	50.00 ± 1.73 b
Occoruro	2.19 ± 0.57 a	2.03 ± 0.46 b	50.67 ± 1.17 ab	49.33 ± 2.75 b
Media	**5.030**	**5.800**	**50.42**	**49.67**
2017–2018				
Andenes	6.40 ± 2.86 a	4.79 ± 1.33 b	47.54 ± 7.71 a	44.90 ± 0.70 a
Maras	2.69 ± 0.37 a	2.65 ± 0.37 a	45.28 ± 1.74 a	45.06 ± 0.43 a
Huanoquite	5.73 ± 1.15 a	4.42 ± 1.03 b	57.63 ± 1.79 a	45.77 ± 5.80 b
Chilca	2.51 ± 0.24 a	1.98 ± 0.61 b	56.15 ± 2.51 ab	51.26 ± 5.51 b
Media	**4.332**	**3.460**	**56.89**	**48.52**
	Hectoliter weight (kg hl^{-1})		**Plant height (cm)**	
2016–2017				
Huanoquite	77.00 ± 0.28 a	78.40 ± 0.57 a	102.00 ± 0.00 b	97.90 ± 0.57 c
Andenes	76.40 ± 1.44 a	78.93 ± 2.44 a	106.67 ± 2.89 ab	94.33 ± 11.02 b
Occoruro	78.53 ± 1.01 a	78.93 ± 0.23 a	99.33 ± 3.79 ab	97.33 ± 5.51 a
Media	**77.47**	**78.93**	**102.670**	**96.520**
2017–2018				
Andenes	76.00 ± 1.14 a	77.20 ± 0.80 a	103.33 ± 4.73 a	96.67 ± 8.02 b
Maras	76.27 ± 1.80 b	80.40 ± 0.00 a	87.33 ± 2.52 a	79.67 ± 2.31 b
Huanoquite	76.93 ± 1.15 a	72.80 ± 4.72	103.33 ± 6.66 a	103.00 ± 2.00 a
Chilca	75.60 ± 1.44 b	77.87 ± 0.61 a	83.00 ± 2.65 a	78.00 ± 3.00 a
Media	**76.27**	**75.34**	**98.00**	**86.890**
	Spike size (cm)		**N tillers/plant**	
2016–2017				
Huanoquite	9.35 ± 0.35 a	9.80 ± 0.35 a	662.00 ± 9.90 a	557.00 ± 166.88 a
Andenes	10.13 ± 1.33 a	9.43 ± 0.51 a	920.00 ± 202.00 a	652.00 ± 60.00 a
Occoruro	9.27 ± 0.67 a	9.03 ± 0.60 a	551.00 ± 19.14 a	454.00 ± 22.14 a
Media	**9.580**	**9.420**	**711.000**	**554.330**
2017–2018				
Andenes	9.00 ± 0.21 a	8.33 ± 0.06 a	479.33 ± 40.50 a	450.00 ± 111.66 a
Maras	7.67 ± 0.58 a	8.00 ± 0.06 a	419.33 ± 14.74 a	381.33 ± 56.23 a
Huanoquite	8.33 ± 0.58 a	9.33 ± 1.15 a	497.33 ± 29.02 ab	550.67 ± 11.93 a
Chilca	7.93 ± 0.81 a	9.27 ± 0.10 a	450.00 ± 58.62 a	404.57 ± 75.16 a
Media	**8.230**	**8.730**	**461.500**	**446.640**
	N grains/spike		N spikes/m^2	
2016–2017				
Huanoquite	40.00 ± 1.41 a	55.00 ± 1.41 a	471.00 ± 15.56 a	398.00 ± 96.17 a
Andenes	61.67 ± 12.90 a	68.33 ± 3.06 a	662.00 ± 74.65 a	588.00 ± 26.10 a
Occoruro	44.33 ± 3.21 a	40.33 ± 1.53 b	468.00 ± 26.50 a	395.00 ± 6.11 a
Media	**48.670**	**54.550**	**533.670**	**460.330**
2017–2018				
Andenes	50.67 ± 4.73 a	52.67 ± 5.51 a	446.67 ± 37.86 a	437.67 ± 115.85 a
Maras	39.00 ± 3.61 a	40.67 ± 3.79 a	402.00 ± 6.00 a	366.67 ± 51.86 a
Huanoquite	53.67 ± 9.81 a	56.00 ± 4.58 a	485.00 ± 30.51 ab	537.67 ± 8.14 a
Chilca	43.00 ± 7.21 a	49.00 ± 4.58 a	413.33 ± 54.31 a	364.67 ± 76.17 a
Media	**46.590**	**49.590**	**436.750**	**426.670**

$\bar{x}$ = average, SD = standard deviation. Varieties with the same letter are not significantly different according to Duncan's multiple comparison at 5% probability.

kg hl^{-1} and the lowest average with the INIA 419 San Francisco variety in the Huanoquite locality with 72.80 kg hl-1 (Table 6).

3.5.4. Plant height (cm)

For this variable the highest averages during the two campaigns were recorded for variety INIA 440 K'ANCHAREQ in the Andenes locality with 106.67 cm (2016–2017) and 103.33 cm (2017–2018). The lowest value in the 2016–2017 campaign was recorded for variety INIA 419 San Francisco in the Andenes locality (94.33 cm) and in the 2017–2018 campaign the lowest value corresponded to variety INIA 419 San Francisco in the Chilca locality (78.00 cm) (Table 6).

3.5.5. Spike size (cm)

Table 7 shows that during the 2016–2017 campaign the INIA 440 K'ANCHAREQ variety in the Andenes locality obtained a larger

Table 7
Results of industrial quality trial of wheat flour of the INIA 440-K'ANCHAREQ variety.

Characteristics	INIA 440 K'ANCHAREQ	INIA 405 San Isidro	INIA 419 San Francisco
Hectolitric Weight (kg hl^{-1})	76.8 ± 1.32	74.81 ± 5.41	77.07 ± 3.52
% Hardness	12.5 ± 1.32	19.33 ± 6.83	25.33 ± 1.44
% Flour yield	52.94 ± 4.93	51.67 ± 4.16	52.9 ± 0.59
% Protein	7.69 ± 0.2	7.71 ± 0.19	7.89 ± 0.3
% Flour moisture	15.78 ± 0.96	15.8 ± 1.49	15.05 ± 0.69
% Ash	0.92 ± 0.08	0.77 ± 0.05	0.79 ± 0.3
% Wet gluten	15.32 ± 4.17	21.62 ± 1.09	30.45 ± 2.56
% Dry gluten	4.94 ± 1.15	6.82 ± 0.41	9.95 ± 0.65
Gluten Index	99.3 ± 1.15	84.67 ± 3.51	94 ± 8.72
Mixogram Data			
Development time (min)	3.53 ± 0.2	2.45 ± 0.61	2.7 ± 0.3
Beak formation height (cm)	7.42 ± 0.53	6.8 ± 0.09	8.32 ± 0.28

Source: UNALM Laboratory - PIPS in Cereals and Andean Grains, August 2019.

spike size (10.13 cm), while the INIA 419 San Francisco variety in the Occoruro locality obtained the smallest spike size (9.03 cm). In the 2017–2018 season, variety INIA 419 San Francisco in the Chilca locality reported the largest spike size (9.27 cm) and the smallest spike size was recorded for variety INIA 440 K'ANCHAREQ in the Maras locality (7.67 cm) (Table 6).

3.5.6. N° of tillers/plant

During the 2016–2017 campaign the highest number of tillers/plants was reported for INIA variety 440 K'ANCHAREQ at the Andenes locality (920) and the lowest number of tillers/plant for INIA variety 419 San Francisco at the Occoruro locality (454). In the 2017–2018 season both the highest and lowest tillers were reported for variety INIA 419 San Francisco in the localities of Huanoquite (550.67) and Maras (381.33) (Table 6).

3.5.7. Grains/spike

Regarding this variable in Table 6 it is observed that in the 2016–2017 campaign, the highest value of grains/spike was obtained with the variety INIA 419 San Francisco in the locality Andenes (68.33) and the lowest value of grains/spike was obtained with the variety INIA 440 K'ANCHAREQ in the locality Huanoquite (40). In the 2017–2018 season the highest value of grains/spike was obtained with the variety INIA 419 San Francisco in the locality of Huanoquite (56) and the lowest value of grains/spike was obtained with the variety INIA 440 K'ANCHAREQ in the locality of Maras (39).

3.5.8. Spikes/m^2

For the 2016–2017 campaign it could be observed that the highest number of spikes/m^2 was recorded for the variety INIA 440 K'ANCHAREQ in the locality of Andenes (662) and the lowest number of spikes/m^2 for the variety INIA 419 San Francisco in the locality of Occoruro (395). In the 2017–2018 season both the highest and lowest number of spikes/m^2 were recorded for variety INIA 419 San Francisco for the localities of Huanoquite and Chilca respectively with values of 537.67 and 364.67 (Table 6).

3.6. Yellow rust disease severity evaluations

In the Andenes locality the incidence of fungal disease is lower, and at the treatment level the INIA 440-Kanchareq (Fig. 2a) variety was found to be immune compared to the H-1254 (Fig. 2d) line (infection coefficient of 1.55) and the local variety INIA - 419 San Francisco (Fig. 2c) (infection coefficient of 0.13). Comparing the infection behavior of *Puccinia striiformis f. sp. tritici* in the localities of Andenes, Maras, Huanoquite and Chilca (Fig. 2), it is evident that line H - 1246 showed a favorable response to stripe rust disease, showing trace samples at the leaf level. Likewise, through a combined analysis for comparison of locality means for Area of progress under the disease progress curve (AUDPC) using Duncan's test at 0.05, it was shown that in the Andenes locality the incidence of the fungal disease is lower, and at the treatment level the H - 1246 line was found to be immune compared to the H - 1254 line and the local variety INIA - 419 San Francisco (Fig. 2b).

The relationship between wheat rust and the varieties evaluated is inversely proportional, because the greater the rust affection, the lower the yields obtained, as shown in Table 6, Fig. 2b.

3.7. Industrial quality trials

The results of the industrial quality trials showed that the INIA 440 K'ANCHAREQ variety reported the highest values for flour yield percentage, ash percentage, gluten index and development time. INIA 405 San Isidro had the highest values for percentage of moisture in flour and INIA 419 San Francisco had the highest averages for hectoliter weight, percentage of hardness, percentage of protein, percentage of wet gluten, percentage of dry gluten and peak formation height (Table 7).

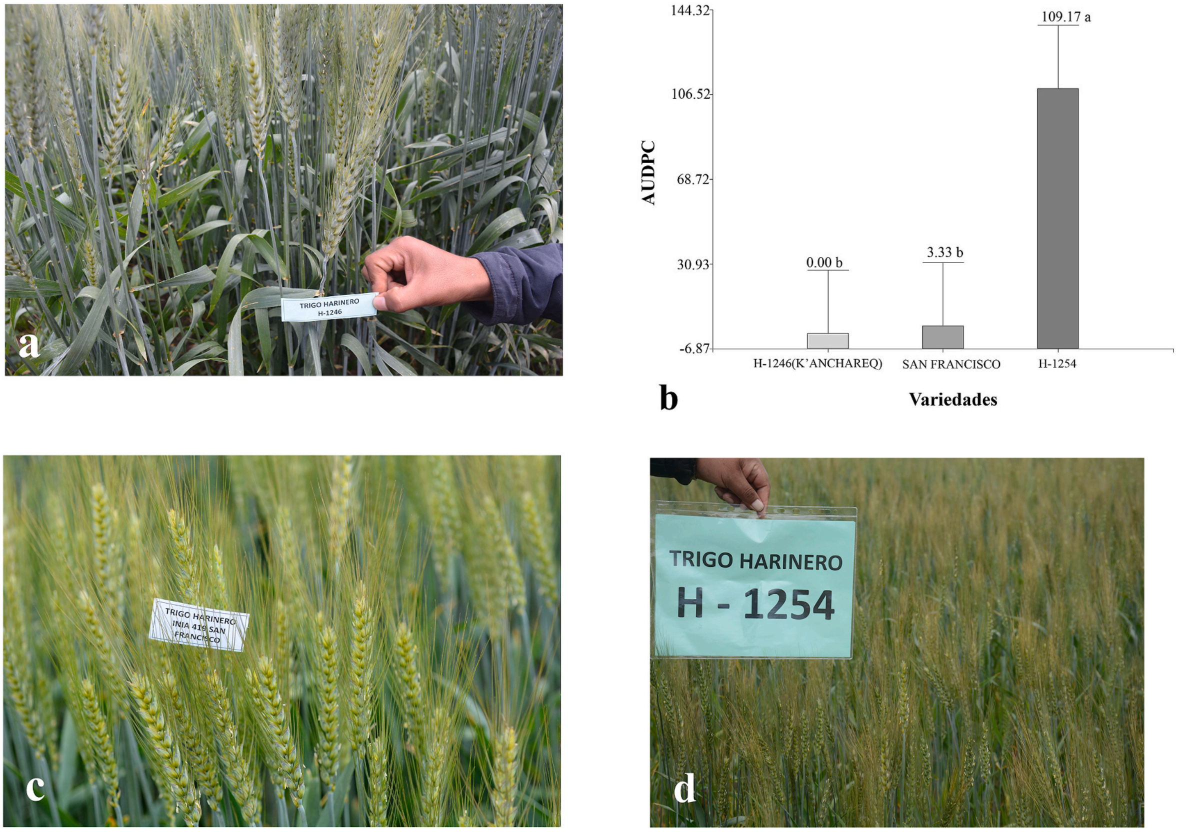

Fig. 2. Response to wheat stripe rust H-1246 (a), comparison of AUDPC means for stripe rust response among varieties (b), response to stripe rust San Francisco wheat (c) and response to stripe rust H-1254 wheat (d).

4. Discussion

It was observed that the INIA 440 K'ANCHAREQ variety shows a clearly different expression in twelve qualitative characteristics compared to the control varieties, making it distinct, homogeneous and stable, according to the factors established by the International Union for the Protection of New Varieties of Plants [14].

Research on the INIA 440 K'ANCHAREQ variety in different environments has shown the results of its adaptation and stability in its quantitative and qualitative characteristics compared to the varieties currently cultivated. In this regard Braun et al. [15] point out about multienvironment trials that modern wheat cultivars often show a wide adaptation to different geographical, environmental and management conditions, while Ramírez et al. [16] mention that advances in grain yield have improved over the years and the genotypes with the best response to high yields, short biological cycles and high productivity are the genotypes of recent formation. In addition, the use of disease-tolerant varieties or the application of fungicides and good agronomic control management leads to better yields and therefore an adequate hectoliter weight for the milling industry [17]. On the other hand, plant breeding has shown an improvement in productive characteristics such as yield and hectoliter weight [18].

Regarding yield during the 2017–2018 season the INIA 440 K'ANCHAREQ variety in the Andenes locality obtained an average of 6.4 t ha^{-1}, a result similar to that obtained by Cuba [19] who found a yield of 6.73 t ha^{-1} in two districts Taray and Zurite Cusco, Peru. Quispe [20] obtained higher values for the flour wheat variety INIA 436 Huamanguino with 8.88 t ha^{-1} in Ayacucho, Peru.

For the case of thousand grain weight the INIA 440 K'ANCHAREQ variety during the two seasons evaluated in both Occoruro and Huanoquite localities reported similar means (50.67 and 57.63 g) to that reported by Suarez [21] for the advanced wheat line UNC - 103 under conditions of Junín, Peru with 51.6 g.

Regarding plant height in the 2016–2017 and 2017–2018 production seasons the INIA 440 K'ANCHAREQ variety obtained the highest reports in the Andenes locality with 106.67 cm and 103.33 cm respectively, results higher than those obtained by Esteban [22] who obtained averages between 77.37 and 90.52 cm for five spring wheat varieties from CIMMYT Mexico resistant to rust in conditions of Junín, Peru.

In the 2016–2017 season, the largest spike size was observed with the INIA 440 K'ANCHAREQ variety in the Andenes locality (10.13 cm), this result is superior to those reported by Santos and Marza [23] who obtained averages between 9 and 9.27 cm of spike length for genotypes L329 and L315 in edaphoclimatic conditions of the Bolivian Altiplano.

The highest average number of grains per spike in the two seasons evaluated was reported by the INIA San Francisco variety in the

Andenes and Huanoquite locations (68.33 and 56, these results are higher than those of Quispe et al. [24] who for 138 flour wheat lines obtained an average of 52.9 under Bolivian conditions. The differences in these characteristics may be due to the difference in the lines evaluated, environment and agronomic management [25].

Sierra [26] in the localities of Andenes and Taray in Cusco, observed the damage produced by four rust races (Yr2, Yr6, Yr7 and Yr 27) in flour wheat lines (*Triticum aestivum* L.); determining that the most aggressive race is Yr2. They were able to select 20 lines with resistance to the four races of stripe rust with yields between 6.66 and 8.38 t ha-1. On the other hand, in Argentina Carmona and Sautua [27] point out that stripe rust disease (*Puccinia striiformis*) in the wheat crop, is always sporadic and is reduced to regions with lower average temperatures. The use of genotypes tolerant to this fungus will reduce losses in physical quality and grain yield [28].

The INIA 440 K'ANCHAREQ variety has baking quality due to its characteristics presented in the industrial quality trials, according to Ale [4]; the industrial quality of wheat has a transcendental impact on the reduction of costs, and consequently on its market price. On the other hand, the characteristics of the industrial quality trials of this variety would indicate that it is a cultivar suitable for industrial baking [29]. The results found as hectoliter weight, hardness and protein were lower than reported by Martínez et al. (2017) who reported values higher than 79 kg hl^{-1}, 50% and 11% respectively for Mexican conditions.

Regarding the percentage of ash Castillo and Matos [30] for five varieties evaluated in Peru reported a mean of 0.61%, being lower than the research work, this difference could be due to the flour extraction yield (Molfese et al., 2014). On the other hand, the moisture percentage was similar with 13–15% being in an optimal range [31]. The percentage of wet gluten obtained by the INIA San Francisco variety was similar to that obtained by Castillo and Matos [30]; which classifies this variety in group 1 corresponding to corrective wheat for industrial baking [32].

In relation to development time, values fluctuated between 2.45 and 3.53 min, values similar to those obtained by Buendía-Ayala et al. [28] who obtained averages between 2.8 and 3.2 min for four commercial wheat varieties and two experimental lines under conditions in Juchitepec, Mexico.

The efficiency of adaptation trials is influenced by genetic and environmental components and plays an important role in the physical quality of wheat grain [33]. The evaluation of trials in different seasons and locations allowed obtaining a genotype with good yield, rust resistance, adaptation to different production conditions and with the quality required for the national baking industry, which will allow surpassing the commercial varieties currently planted [34].

5. Conclusions

INIA 440 - K'ANCHAREQ is a new variety that showed adaptation to wheat producing regions between the altitudinal levels of 2875–3550 m in the regions of Cusco and Apurimac, demonstrating production capacity and profitability in farmers' fields. Through adaptation and efficiency trials, the INIA 440 - K'ANCHAREQ flour wheat variety achieved superior averages in agronomic variables compared to local varieties. Its rust resistance and good response to industrial quality trials position it as an excellent variety for the national baking industry and make it a profitable and safe alternative for the farmer, which facilitates its adoption in the main producing areas of the country.

This study highlights the strategic alliance with international centers such as CIMMYT for access to genetic material. Another useful aspect was the use of participatory research methodologies and evaluations in multiple environments, which favored the selection processes of the new wheat variety. These methodologies also made it possible to collect the selection criteria for the new cultivars, which will benefit the rapid adoption by producers and their access to the flour production market for baking. However, it is important to continue emphasizing the development of new varieties with the application of genetic improvement involving the actors of the wheat value chain.

Declarations

Author contribution statement

Rigoberto Estrada Zúniga: Conceived and designed the experiments; Wrote the papers.
Carmen N. Vigo; Leidy G. Bobadilla: Analyzed and interpreted the data; Wrote the paper.
V. Gonza: Performed the experiments; Contributed reagents, materials, analysis tools or data.
Michael B. Manotupa Tupa: Performed the experiments; Wrote the paper.
H. Carreño: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

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Data included in article/supp. material/referenced in article.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare no competing interests.

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