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The Genotypic and Phenotypic Basis of Chickpea (*Cicer arietinum* L.) Cultivars for Irrigation-Based Production in Ethiopia

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Abstract

Development of irrigation-based chickpea production is considered the most important alternative approach in combating climate change and maximizing productivity, especially in moisture-stress areas and in areas where water and land for irrigation is available. In central Ethiopia, where production of chickpea (especially *Kabuli* type) is becoming an important part of agriculture, although many superior varieties (both *desi* and *Kabuli* types) are available, they have been evaluated and released based on rainfed production. Hence, there is an urgent need for evaluation of varieties suited for irrigation-based production. Towards this goal, during the 2012/13 growing season, 14 *Kabuli* genotypes (previously introduced) and 24 *desi* genotypes (nurseries obtained from ICRISAT) were evaluated independently at three and one locations respectively (*Kabuli* at Debre Zeit, Ambo and Werer; *desi* at Debre Zeit) for production adaptation under irrigation. The parameters evaluated were date of maturity, 100-seed weight and yield. Overall, while most Kabuli genotypes showed high adaptability to irrigation-based production at all locations, four Kabuli genotypes (X96TH-52-14/2000 = 106.7DAS, FLIP-02-39C = 107DAS, X98TH-51-1-3 = 107.9DAS and ICCV-07313 = 107DAS) were found to be earlier in maturity; two genotypes (ICCV-07313 = 42.5 g and ICCV-04305 = 37.8 g) were identified as having high 100-seed weight and one genotype (ICCV-05309 = 3228.8 kg/ha or 32 quintals/ha) out yielded all genotypes across locations. The result of combined analysis indicated five promising genotypes showing more than 20 kg/ha yield on average. All *desi* varieties showed maturity dates of under four months; six genotypes showed higher 100-seed weight and eight genotypes showed promising yield responses (> 2000 kg/ha). From these preliminary results, it can be deduced that irrigation can play a significantly complementary role to the rainfed system, provided the genetics by management is optimized through research and innovation.

Keywords: chickpea, combined, genotypes, irrigation, rainfed, yield

1. Introduction

Chickpea (*Cicer arietinum*) is one of the most important cool-season annual grain legumes grown in more than 50 countries (89.7% area in Asia, 4.3% in Africa, 2.6% in Oceania, 2.9% in the Americas and 0.4% in Europe) with India taking the largest share (64%) of the global production. Countries such as Pakistan, Turkey, Iran, Australia, Ethiopia, Canada, Mexico and Iraq are also important chickpea-producing countries (Gaur et al., 2012). In Ethiopia, chickpea holds third place as a grain legume both by area coverage and volume of production, next to faba bean and haricot bean (CSA, 2016). There are two distinct types of chickpea identified (Muehlbauer et al., 1982; Jukanti et al., 2012):

Desi chickpea: It has a thick, colored seed coat. The common seed colors include various shades and combinations of brown, yellow, green and black. The seeds are generally small and angular with a rough surface. The flowers are generally pink; however, some *desi* types have white flowers.

Kabuli chickpea: The *Kabuli* type chickpeas are characterized by white seeds with ram's head shape, smooth surface and thin seed coat. The flowers are generally white. As compared to *desi* types, the *Kabuli* types have higher levels of sucrose and lower levels of fiber. The *Kabuli* types generally have large seeds and receive higher market price than *desi* types; the price value in *Kabuli* type generally increases as the seed size increases.

Chickpea is cultivated for different values it provides, whether in nutrition, food and environmental rehabilitation, or in cash generation. Its nutritional value, medicinal value and market value, as compared to other annual crops, are some of the most important merits for which the crop is grown in Ethiopia. Nutritionally, the chickpea seed has 38-59% carbohydrate, 3% fiber, 4.8-5.5% oil, 3% ash, 0.2% calcium and 0.3% phosphorus. Digestibility varies from 76-78% for its protein and 57-60% for its carbohydrate (Hulse, 1991; Kumar et al., 2016). Pulses such as chickpeas are important sources of macronutrients, containing almost twice the amount of protein compared to cereal grains (Brick et al., 2003). They are good sources of fiber, folic acid, manganese, iron, magnesium, copper and zinc (Brick et al., 2003).

Medicinally, a cooked chickpea-milk (4:1) mixture has been found beneficial for infants, effectively controlling diarrhea (Jukanti et al., 2012). In addition, chickpea has been reported as an important means in controlling bronchitis, cholera and constipation; acids in chickpea seed are supposed to lower blood cholesterol levels (Jukanti et al., 2012). Regular consumption of pulses such as chickpeas prevents diabetes and reduces risk of heart disease (Jukanti et al., 2012).

The local consumption of chickpea in different forms for household use and local market has increased with time (CSA, 2015). Virtually all domestic pulse crop production is marketed through processors for export but the majority is sold on the local market and consumed locally. However, the quantity and quality of the product produced limit the ability of domestic producers to influence world markets and to consistently produce sufficient quantities to be a reliable supplier for large users.

Though most of the production of the crop in Ethiopia is restricted to rainfed fields, chickpea is assumed to be the most adaptive to drought, and responds better to small irrigation than other legume crops. If it is irrigated at the right time with the required amount of water, the yielding potential of the crop could be increased. Egypt and Sudan produce chickpea solely using irrigation and Egypt takes the first place in productivity with about 20 quintal/ha. Egypt irrigates the crop 1-2 times during the early stage of crop emergence and during flowering and maturity, while in Sudan chickpea is irrigated 5-7 times. Apart from the availability of irrigation water and land, availability of the most responsive varieties of chickpea suited to irrigation is very important. In Ethiopia, the potential suitable land and water resources for irrigation-based chickpea production surpasses many thousand hectares. Accordingly, the demand for varieties suitable for irrigation is soaring. To address this and beyond, the National Chickpea Improvement Program has put in place over location response assessment of pipeline germplasm to evaluate and characterize their inherent responses, and its stability. Therefore, this study is designed to develop cultivars suited for an irrigation-based production system in Ethiopia.

2. Materials and Methods

2.1 Description of Study Area

Experiments were conducted at Debre Zeit Agricultural Research Center, Werer Agricultural Research Center and Ambo Plant Protection Research Center at the Ethiopian Institute of Agricultural Research during 2013-2014. The agro-climatic conditions, altitude and soil characteristics of the study areas are presented in Table 1 below.

Table 1. Agro-climatic conditions, altitude and soil characteristics of the study areas

No.	Center	Altitude (m.a.s.l.)	Average Annual rainfall (mm)	Temperature (°C)		Soil type	PH
				Min (°C)	Max (°C)		
1	Debre Zeit	1900	851	8.9	28.3	Vertisols	7.45
2	Werer	740	533	15.2	32.5	Fluvisols	7.5-8.5
3	Ambo	2175	1260.90	10.02	26.89	Pellic Vertisols	6.78

2.2 Treatments

A total of 14 early *Kabuli* chickpea lines were promoted from preliminary variety trial (PVT) and 24 *desi* chickpea lines introduced from ICRISAT were grown on-station at Debre Zeit, Ambo and Werer Agricultural Research Centers using irrigation. Planting was in four rows of plot of 4 m long and 1.2 m wide in Randomized Complete Block Design (RCBD) with three replications as shown in Figure 1. Planting was done on 10/01/2012 (for *Kabuli*) and 05/01/2012 (for *desi*) at Debre Zeit, 06/01/2012 at Ambo and 24/12/2012 at Werer since rainfall at all stations terminate before planting time and there is a dry spell following it. At all locations, the trials were surface irrigated four times using furrow irrigation and selection was made on the basis of date of maturity, 100-seed weight and yield; analysis was done using SAS software.

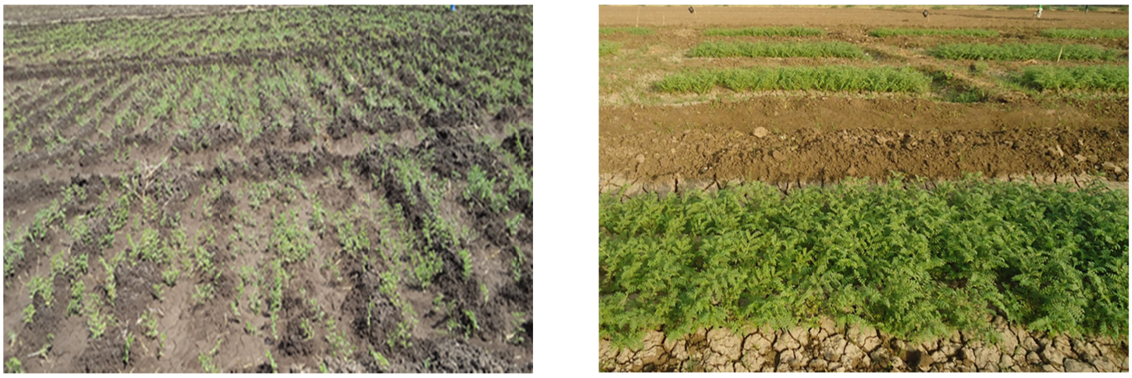

Figure 1. A pictorial view of the field layout to evaluate chickpea genotypes for adaptation to irrigation-based production

3. Result and Discussion

All the genotypes under treatment were produced and harvested. There was a significant difference (P > 0.05) among the genotypes in their date of maturity. Dates of maturity of the genotypes differed at different locations, possibly due to irrigation management and thermal level. Though all the genotypes were early-maturing, according to the result of combined analysis, only four genotypes (X96TH-52-14/2000 = 106.7DAS, FLIP 02-39C = 107DAS, X98TH-51-1-3 = 107.9DAS and ICCV-07313 = 107DAS) matured earlier than the others, including the check, in the entire trial (Table 2). Three genotypes at Debre Zeit, one genotype at Ambo and five genotypes at Werer were found maturing earlier than others at their specific locations (Table 2). Similarly, the delay in days to 50% flowering causes delay in maturity. Bakhsh et al. (2007) and Kanouni (2001) have reported delay in flowering due to irrigation. In conclusion irrigation during any phase of development significantly increases the time required for flowering, podding and physiological and harvest maturity.

Table 2. Date of maturity of *Kabuli* early under irrigation at different locations (Debre Zeit, Ambo and Werer)

No.	Treatment/Variety	Date of Maturity (days)			
		Debre Zeit	Ambo	Werer	Means
1	FLIP 02-13C	120a	126ab	116ab	120.7abc
2	FLIP 01-2C	118a	128ab	120ab	122a
3	FLIP 01-3C	118a	135a	121.7ab	125a
4	FLIP 03-59C	116ab	135a	107bc	119abcd
5	ICCV-05309	115ab	128ab	99cd	114bcde
6	FLIP 01-56C	115ab	126ab	122a	120.9ab
7	X96TH-52-14/2000	114.7ab	121ab	95cd	106.7e
8	FLIP 02-39C	114ab	120ab	91.7d	107e
9	ICCV-04305	110bc	135a	95cd	113cde
10	X98TH-51-1-3	110bc	114b	100.7cd	107.9e
11	ICCV-07313	109.7bc	121ab	95cd	107e
12	Chefe	109bc	128ab	95.7cd	112.9de
13	Ejere	105c	127ab	95cd	110.8e
14	DZ-10-4	104c	128ab	92d	111e
	Mean	112.8	126.6	103	114
	CV	4	7.9	8	7
	LSD at 5%	7.9	16.8	14.7	3.5

Note. Means followed by different letters in the same column differ from each other by the F-Test (P < 0.05).

In line with these results, the long standing problem of population stand establishment has remained one of the key challenges in irrigated chickpea. In a controlled on-station trial with 3 factors at 2 levels arranged in 8 treatments, *i.e.*, *two varieties* × *seed priming and non-priming* × *pre-watered and post-watered plot*; it was observed that seed priming in pre-watered plot gave the highest germination (98-100%) compared to post-watered which gave 75-85% (Table 3). Concurrently, it was also observed that phenological responses of Kabuli primed seed on pre-watered plot flowered earlier than other setups. This preliminary observation requires further experimentation and validation before substantive publication in a future issue of the journal.

Table 3. Effects of seed priming on two chickpea varieties under different irrigation schemes

Variety	Pre-watered plot before planting						Post-watered plot after planting						Phenology	
	SPT			NPT			SPT			NPT				
	GP (%)	DF	SW (1-9)	GP %	DF	SW (1-9)	GP (%)	DF	SW (1-9)	GP %	DF	SW (1-9)	DF	DM
Dimtu	83	41	5	100	43	5	90	43	5	55	40	5	47	110
Habru	99	44	3	100	48	3	55	48	1	30	49	3	50	111

Note. SPT = Seed priming treatment, NPT = Non-priming treatment, GP = Germination percentage, DF = Days to flowering, SW = Seedling wilt DM = Days to maturity.

There was also a substantial difference between the genotypes for 100-seed weight at 0.05 levels. The 100-seed weight of the genotypes varied across locations; the maximum 100-seed weight for FLIP 02-13C was 45 g followed by FLIP 01-2C (41.5 g) and FLIP 01-3C (39 g) at Debre Zeit, although the 100-seed weight of these materials at Ambo and Werer were decreasing by an average of 10 g (Table 4).

The 100-seed weight of only two genotypes (ICCV-07313 = 42.5 g and ICCV-04305 = 37.8 g) were found superior across all locations. Otherwise, 100-seed weight of three genotypes at Debre Zeit, two genotypes at Ambo and three genotypes at Werer were found higher than other genotypes at their respective locations. Similarly, two irrigations at branching and pod formation stages were shown better seeds pod-1 and 1000-seed weight, as reported by Ray et al. (2011).

Table 4. Mean 100-seed weight of *Kabuli* early under irrigation at different locations

No.	Treatment/Variety	100-seed weight			
		Debre Zeit	Ambo	Werer	Location means
1	FLIP 02-13C	45a	30.5c	29.8d	31c
2	FLIP 01-2C	41.5b	31.9bc	30d	32c
3	FLIP 01-3C	39bc	31.9bc	28d	31c
4	FLIP 03-59C	37.5cd	31.6bc	28.6d	31.8c
5	ICCV-05309	35de	29c	24e	28d
6	FLIP 01-56C	34e	32.7bc	29.8d	33c
7	X96TH-52-14/2000	34e	22d	27.6d	26.5d
8	FLIP 02-39C	33ef	31.9bc	28.7d	31c
9	ICCV-04305	33ef	37.7ab	34b	37.8b
10	X98TH-51-1-3	33ef	28cd	22.6e	26d
11	ICCV-07313	31.4gf	42a	40a	42.5a
12	Chefe	29.5gh	32.8bc	30.3cd	32c
13	Ejere	27.8h	37.7ab	32.9bc	36.6b
14	DZ-10-4	12i	11e	10.9f	11e
	Mean	33	30.9	28	30.9
	CV	4	12	5.7	8
	LSD at 5%	2.6	6	2.8	1

Commonly, FLIP 02-13C genotypes had demonstrated higher yield than the released variety used as a standard check (Ejere, Chefe and Dz-10-4) at Debre Zeit (Tables 5 and 6). However, the result of combined analysis showed that only one genotype (ICCV-05309 = 3228.8 kg/ha or 32 quintals/ha) could out yield the other genotypes over all locations combined. Based on the current available genotypes assessment, we are convinced, from the very good yield performances of X96TH-52-14/2000 = 2489kg/ha, FLIP 02-13C = 2261.8 kg/ha, FLIP

03-59C = 2222.5 kg/ha, ICCV-04305 = 2213.5 kg/ha, and FLIP 02-39C = 2094.5 kg/ha, that irrigation is great avenue for research and development in chickpea production in Ethiopia. Similar to this study, increase in grain yield of chickpea under irrigation has been reported by many authors (Anwar et al., 2003; Pacucci et al., 2006; Bakhsh et al., 2007; Kang et al., 2008; Vinayak et al., 2012). The better performance of certain genotypes after irrigation, as compared to main season, reaffirms the decision to embark upon irrigation systems at scale.

Table 5. Comparison of mean date of maturity (DM), 100-seed weight (HSW) and yield of *Kabuli* chickpea early under rainfall and irrigation conditions at Debre Zeit

Genotypes	Variables (Irrigation)			Variables (Rainfall)			Genotypes
	DM	HSW (g)	Yield (kg/ha)	Yield (kg/ha)	HSW (g)	DM	
FLIP 02-13C	120a	45a	4133a	2300.5b	32def	124ab	FLIP 02-13C
FLIP 01-2C	118a	41.5b	3600ab	2848.6a	34.8cd	123ab	FLIP 01-2C
FLIP 01-3C	118a	39bc	3291bc	2562.5ab	33de	123ab	FLIP 01-3C
FLIP 03-59C	116ab	37.5cd	3204bcd	2964.8a	33.9d	118.7b	FLIP 03-59C
ICCV-05309	115ab	35de	3183bcd	1038cde	28.7f	126a	ICCV-05309
FLIP 01-56C	115ab	34e	3169bcd	2989a	33.8d	123.7ab	FLIP 01-56C
X96TH-52-14/2000	114.7ab	34e	2983.8bcd	1536c	29.8ef	112d	X96TH-52-14/2000
FLIP 02-39C	114ab	33ef	2973.6bcd	1351.9cd	31.9def	122.7ab	FLIP 02-39C
ICCV-04305	110bc	33ef	2968.5bcd	1080.6cde	40b	122ab	ICCV-04305
X98TH-51-1-3	110bc	33ef	2781.9cd	1005.6de	30ef	108d	X98TH-51-1-3
ICCV-07313	109.7bc	31.4gf	2615.7cde	730.6ef	49a	112.3cd	ICCV-07313
Chefe	109bc	29.5gh	2453.7de	2256b	32.5de	111d	Chefe
Ejere	105c	27.8h	1946e	1543c	38bc	111d	Ejere
DZ-10-4	104c	12i	1883e	352f	10.8g	118bc	DZ-10-4
Mean	112.8	33	2942	1754	32.8	118.4	Mean
CV	4	4	15.9	17	6.5	3	CV
LSD at 5%	7.9	2.6	789	520	3.5	6	LSD at 5%

Table 6. Mean yield of *Kabuli* early under irrigation over location

No.	Treatment/Variety	Mean yield (kg ha^{-1})			
		Debre Zeit	Ambo	Werer	Location Means
1	CFLIP 02-13C	4133a	3254cd	557.6ef	2261.8bcde
2	FLIP 01-2C	3600ab	2590.8cd	626.5e	1890f
3	FLIP 01-3C	3291bc	2820.7c	667e	2152cdef
4	FLIP 03-59C	3204bcd	3928.9ab	855d	2222.5bcdef
5	ICCV-05309	3183bcd	4315.9a	1237bc	3228.8a
6	FLIP 01-56C	3169bcd	2684cd	454.7f	2040.9def
7	X96TH-52-14/2000	2983.8bcd	2924c	1339ab	2489bc
8	FLIP 02-39C	2973.6bcd	2689.7	977.9d	2094.5def
9	ICCV-04305	2968.5bcd	1655e	1385a	2213.5bcdef
10	X98TH-51-1-3	2781.9cd	2074.8de	913.6d	1923ef
11	ICCV-07313	2615.7cde	716.5f	1315ab	1325.9g
12	Chefe	2453.7de	3233bc	1220bc	2540.9b
13	Ejere	1946e	2729.9cd	1158c	2357bcd
14	DZ-10-4	1883e	2886.5c	958.6d	2378.9bcd
	Mean	2942	2750	976	2222.85
	CV	15.9	15	8.7	17
	LSD at 5%	789	709.9	142.7	168.7

In case of *desi* types, all of the genotypes reached their maturity date in under four months. The 100-seed weight of six genotypes (ICCX-090013-F2-P177-BP = 35 g, ICCX-090013-F2-P216-BP = 34.8 g, ICCX-090013-F2-P276-BP = 34.7 g, ICCX-090013-F2-P248-BP = 33 g, ICCX-090013-F2-P107-BP = 32 gm and ICCX-090013-F2-P173-BP = 32 g) were found higher than the other, and also the yield of eight genotypes (ICCX-090013-F2-P216-BP, ICCX-090013-F2-P129-BP, ICCX-090013-F2-P103-BP, ICCX-090013-F2-P215-BP, ICCX-090013-F2-P276-BP, ICCX-090013-F2-P163-BP, ICCX-090013-F2-P173-BP and ICCX-090013-F2-P265-BP) were found promising with respect to high yields (> 20 kg/ha) out of the genotypes under irrigation (Table 7). The same result was reported by Mansur et al. (2010), and Dogan et al. (2012). According to Fardin et al. (2013) growth continued during all growth stages, but for best growth of chickpea and for higher yields, irrigation is better. The influence of disease and insects was minimal during the trial season; this could be an opportunity for studying the limitation of stress levels and their effect on yield and product quality. Because of the new cropping system, the climatic and environmental conditions may not support development of pests, as in the case of the main cropping seasons.

Table 7. Mean date of maturity (DM), 100-seed weight (HSW) and yield of desi chickpea under irrigation over location (The materials were obtained from ICRISAT)

No.	Treatment/Variety	Variables		
		DM	HSW (g)	Yield (kg/ha)
1	ICCX-090013-F2-P177-BP	101.7abc	35.6a	2274.5defghij
2	ICCX-090013-F2-P163-BP	102abc	29fghi	2475.5bcdefgh
3	ICCX-090013-F2-P276-BP	101abc	34.7bc	2466.7bcdefgh
4	ICCX-090013-F2-P234-BP	100abc	30efghi	1936hij
5	ICCX-090013-F2-P120-BP	93c	23.7lm	2422.7cdefghi
6	ICCX-090013-F2-P107-BP	96.7abc	32bcde	2053.7fghij
7	ICCX-090013-F2-P215-BP	107ab	30.5defghi	2748abcde
8	ICCX-090013-F2-P108-BP	104abc	32bcde	1805.6ij
9	ICCX-090013-F2-P147-BP	103abc	30.5defgh	2305defghi
10	ICCX-090013-F2-P103-BP	101abc	23lm	2874.5abcd
11	ICCX-090013-F2-P245-BP	97abc	25jkl	2420.8cdefghi
12	ICCX-090013-F2-P129-BP	108.7a	27.7hijk	2954abc
13	ICCX-090013-F2-P216-BP	98abc	34.8bc	3283.8a
14	ICC-4958	98abc	30defghi	2306defghi
15	ICCX-090013-F2-P145-BP	104abc	31.6def	2225efghij
16	ICCX-090013-F2-P145-BP	102abc	27.6ijk	2363.9cdefghi
17	ICCX-090013-F2-P173-BP	96.7abc	32bcde	2738.9abcde
18	ICCX-090013-F2-P284-BP	94bc	25kl	1659j
19	JL-11	105.7abc	30.9defg	2591.7bcdefg
20	ICCX-090013-F2-P105-BP	96.7abc	22m	2576bcdefg
21	ICCX-090013-F2-P175-BP	98abc	23.6lm	1969ghij
22	ICCX-090013-F2-P265-BP	98abc	32cde	2661abcdef
23	ICCX-090013-F2-P248-BP	97abc	33bcd	1668.5j
24	ICCX-090013-F2-P223-BP	98abc	28ghij	2348cdefghi
	Mean	100.6	29.8	2407.5
	CV	8	6	15.9
	LSD at 5%	13.5	2.9	631

4. Conclusion and Recommendation

The irrigation trial undertaken on promising chickpea genotypes in 2012/13 demonstrated that irrigation is one of the major contributors in chickpea production system. There is untapped potential in production, productivity and quality to be exploited using the irrigation system. All the genotypes sown from Kabuli and *desi* varieties set quality seed at all locations. Except for termites at Werer, and wilt on one genotype at Debre Zeit, the occurrence of disease and insects was not detected. At some locations, the yield of some genotypes stood out as more important for our irrigation trial. Although the genotypes, especially the *Kabuli* types, were introduced for other purposes, they were also found to be adaptable to irrigation-based production. Of these, some genotypes performed better even in main season at Debre Zeit, as evaluated by all parameters used for analysis. From the results, we recommend that, even though all materials were not found equally important for all parameters evaluated, those genotypes which best demonstrated yield, seed size and maturity be included in the breeding program. So, genotypes with high 100-seed weight are used as parents for crossing with genotypes with low 100-seed weight, but giving high yields. It was also interesting to deal with optimization of irrigation frequency, developing responsive and suitable cultivars for the irrigation system and developing G × E stable commercial varieties in the research design. In conclusion, ICCX-090013-F2-P120-BP, FLIP 02-39C, X96TH-52-14/2000, X98TH-51-1-3 and ICCV-07313 for maturity; ICCX-090013-F2-P177-BP, FLIP 02-13C and ICCV-07313 for 100-seed weight; and ICCX-090013-F2-P216-BP, FLIP 02-13C and ICCV-05309 for yield were identified for further breeding work and yield trial for release for irrigation-based production areas.

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