CULTIVAR RELEASE

CISJU21 - New flax cultivar with yield and phenotypic stability

Crop Breeding and Applied Biotechnology
23(2): e44262324, 2023
Brazilian Society of Plant Breeding.
Printed in Brazil
http://dx.doi.org/10.1590/1984-70332023v23n2c16

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Abstract: *The flax cultivar CISJU21, developed by the crop breeding program of the UNIJUÍ, was the result of selection for plants with early flowering, a shorter cycle, greater capsule diameter, optimized weight and higher number of grains per plant, with high yield stability and grain yield in the tested scenarios.*

Keywords: Linum usitatissimum L.*, phenotypic plasticity, innovation, sustainability*

INTRODUCTION

Common flax (*Linum usitatissimum* L.) is a flexible species, in view of the multi-purpose applications for which the plant can be used, such as oil, bran, animal feed, cosmetics and biofuel production (Azevedo et al. 2022). As food, the grain linseed has particularly high levels of fatty acids, fibers, proteins and phenolic compounds, and up to 39% of oil in the grain composition (Loro et al. 2022).

In 2020, the world produced around 3.36 million tons of this oilseed, on an acreage of more than 3.54 million hectares (FAO 2020). Currently, Brazilian linseed production is concentrated in the state of Rio Grande do Sul, on an area of over 10 thousand hectares and exceeding 1,000 kg ha^{-1} grain. One of the limitations for the expansion of the cultivation areas is the scarcity of cultivars that are acclimatized and developed for the edaphoclimatic conditions of the Southern Region of Brazil and available on the market.

In Brazil, only eight flax cultivars are protected and registered by the Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA). This generates opportunities for breeding programs to select new genetic constitutions that maximize the use efficiency of the respective local environmental conditions, to increase grain productivity and quality.

In view of the relevance of common flax for agricultural systems and the limited availability of cultivars, the crop breeding program of Regional University of the Northwest of the State of Rio Grande do Sul (UNIJUÍ), together with the graduate program in Environmental Systems and Sustainability, initiated the selection and development of cultivars that are stable under environmental variations with unvaried high grain productivity for oil production in Rio Grande do Sul.

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Received: 04 January 2023
Accepted: 25 March 2023
Published: 24 May 2023

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BREEDING METHODS

Cultivar CISJU21 was developed by the Breeding Program of the Regional University of the Northwest of the State of Rio Grande do Sul (UNIJUÍ), within the framework of the research project "Grain and Cover Crops", linked to the graduate program Environmental Systems and Sustainability at UNIJUÍ. The development with several selection cycles was initiated in 2010, with germplasm from Catuípe - RS and Ijuí - RS. In May 2010, the populations were sown in Catuípe (lat 28º 26' 12" S, long 54º 00' 33" W, alt 328 m asl) - RS, at low population density (40 seeds m^{-1}; row spacing 17 cm) to maximize genetic variability. During this period, no selection was applied, only the seeds were multiplied for sowing, to ensure well-cultivated plots with high experimental quality.

On June 2011, seeds were sown on five plots (150 m²; total area 750 m²), using a similar plant arrangement for all units. In this cycle, positive mass selection was used, where only plants with flowers with violet petals in the "bud" phase were maintained. All other plants were eliminated, and the others were harvested as a single population, based on the criteria of violet flowers and brown seeds.

In May 2012, the cultivation strategy was the same, although the population method was used to select plants with shorter height, prioritizing a reduced energy investment in non-productive morphological structures and the elimination of plants with flowers and seeds with colors different from those of the desired agronomic ideotype. In 2013 and 2014, a comparable selection method and similar cultural practices as in the previous generation were used. However, selection targeted a reduction in the growth period and early-flowering plants with genetic gain for a shorter crop cycle. To increase the pressure of the cultivation environment on the quantitative inheritance traits (2015 - 2018), bulk seeding was performed at high population density (65 seeds m^{-1}; row spacing 17 cm) in Palmeira das Missões (lat 27º 91' 05" S, long 53º 26' 68" W, alt 639 m asl) - RS. The selections in 2015 addressed plants with a higher number of productive branches. In 2016, priority was given to the selection of plants with a higher number of viable capsules, in 2017, to a larger capsule diameter and in 2018, to a higher weight and number of grains per plant.

In May 2019, the seeds were sent to the Escola Fazenda of UNIJUÍ (lat 28º 43' 81" S, long 54º 00' 61" W, alt 328 m asl) and sown (65 seeds m^{-1}; row spacing 17 cm), with the purpose of multiplying the seeds required for the following tests and removing and excluding atypical plants by "roguing". In this cycle, the desired agronomic ideotype consisted of plants with flowers with violet petals only, uniform height, synchronous flowering and concomitant physiological maturation, as well as brown seeds.

In 2020 and 2021, the distinctness, uniformity and stability (DUS) tests for qualitative inheritance characteristics and minimum descriptors necessary for cultivar protection were carried out, and registered by the Ministry of Agriculture, Livestock and Supply (process 21806.000054/2021), which determined definitive protection from 05/05/2022 to 05/05/2037. Concomitant to the above procedures, the tests of Value for Cultivation and Use (VCU) were carried out in 2020, 2021 and 2022, in six environments with different sowing times. In this stage, cv. CISJU21 was planted together with two controls, dissimilar in a range of characteristics, and commonly cultivated in the Northwestern region of the State of Rio Grande do Sul.

TRAITS AND PERFORMANCE

The elite line called CISJU21, a result of the breeding procedures described above, was subjected to the VCU Tests in 2020, 2021 and 2022. In each test, the genotypes CISJU21, CDC Sorrel (check) and a golden linseed variety (check) were planted in six cultivation environments (E1 (Augusto Pestana – RS: ST:15/04), E2 (Ijuí – RS: ST:15/04), E3 (Catuípe – RS: ST:15/04), E4 (Augusto Pestana – RS: ST:15/05), E5 (Ijuí – RS: ST:15/05), E6 (Catuípe – RS: ST:15/05), in a total of 18 test environments.

The experimental design was randomized blocks in a factorial scheme and, for a better understanding, the effects of the growing seasons (2020, 2021 and 2022) were stratified. Three cultivars were evaluated in six cultivation environments, in three replications, corresponding to a total of 162 experimental plots. Each unit consisted of seventeen 15-m plant rows spaced 18 cm apart, covering a total area of 45.9 m². At full physiological maturity, 10 plants per plot were randomly collected. The following traits were assessed: plant height (PH, cm), number of stem branches (NSB, units), growth cycle (Cycle, days), number of grains per plant (NGP, units), 1000-grain weight (TGW, g) and grain yield (GY, kg ha^{-1}).

Subsequently, the assumptions of the statistical model of additivity, independence of errors, homogeneity and normality of residual variances were tested. Once met, analysis of variance was carried out at 5% probability using the F test to detect the presence of interaction of cultivation environments x cultivars, stratified for each growing season. Significant interactions were broken down to simple effects by Scott Knott grouping for mean ranking, non-significant interactions were partitioned into main effects, using a probability matrix similar to the previous one. To improve the representation of cultivar stability, the method of Genotype + Genotype x Environment Interaction (GGE) was used, based on the dependent variable grain yield.

The cultivar effect was significant for plant height (Table 1), e.g., *or* since in 2020 the golden variety had shorter plants (74.53 cm). Clearly, the cultivars CISJU21 and CDC Sorrel met the requirement for the desired agronomic ideotype with regard to plant height (80 cm). Cultivar CISJU21 had a better performance than the controls for both 1000-grain weight and grain yield.

A lower plant height was observed in environment 6, with late sowing (on July 1), which directly results in reduced stem elongation. In the 2020 tests, the number of stem branches and number of grains per plant were higher in environments 1 and 2 (sowing on April 15 and May 1, respectively. In 2021, abrupt changes were observed in environment 6.

In 2022, the number of grains per plant was only lower in environments 4 and 5 (sowing on June 1 and 15 respectively). In 2020, the trait 1000-grain weight was enhanced by 5 g in environments 2 and 3 (sowing on May 1 and 15, respectively). In 2021, no statistical differences were detected, because a prolonged dry spell possibly contributed to a reduced plant height and lower grain weight.

In 2020, grain yield increased by 1300 kg ha^{-1} in environments 4 and 5 (sowing on June 1 and 15, respectively). In 2021, yields decreased (by 887.78 and 935.11 kg ha^{-1}, respectively) in environments 1 and 6, where sowing occurs at the extremes of the time window recommended for flax in Rio Grande do Sul. According to Gallardo et al. (2014), late sowing of flax can quantitatively and qualitatively affect grain productivity, mainly because the air temperature is not optimal for the crop.

In 2022, significant differences (Table 2) were detected between cultivars in terms of plant height, 1000-grain weight and grain yield. Cultivar CISJU21 had a lower plant height when sown in environments 1 (15/04), 3 (15/05), 4 (01/06), and 6 (01/07). The plant height of the other cultivars was beyond the limits established for the agronomic ideotype. Cultivar CISJU21 produced higher 1000-grain weight when sown early, between late April and the first half of May. Grain yield was maximized in this cultivar when grown in environments where sowing is performed from May 1 to June 1. The timing of sowing of the flax cultivars significantly affects growth and development (Ganvit et al. 2019), as well as

Table 1. Mean clustering for plant height (PH, cm), number of stem branches (NSB, unit), number of grains per plant (NGP, unit), 1000-grain weight (TGW, g) and grain yield (GY, kg ha^{-1}) of cultivar CISJU21 and control cultivars in Value for Cultivation and Use (VCU) tests, in the growing seasons 2020, 2021 and 2022

Cultivars	**2020**					**2021**				
	PH	**NSB**	**NGP**	**TGW**	**GY**	**PH**	**NSB**	**NGP**	**TGW**	**GY**
CISJU 21	78.9a	4.67a	64.24a	5.17a	1267.48a	70.50a	2.88a	82.47a	1.92a	962.15a
CDC Sorrel (check)	81.05a	4.72a	75.02a	4.26b	1054.73b	70.27a	2.66a	80.33a	1.53b	745.66b
G Var (check)*	74.53b	4.25a	66.03a	4.11b	1052.21b	68.19a	3.00a	85.85a	1.54b	756.18b

Cultivation environments

Environments	**2020**					**2021**					**2022**
	PH	**NSB**	**NGP**	**TGW**	**GY**	**PH**	**NSB**	**NGP**	**TGW**	**GY**	**NGP**
E1	93.31a	5.26a	86.25a	4.50b	788.46c	88.66a	2.77b	90.30b	1.71a	887.78a	108.49a
E2	87.31b	5.43a	94.50a	5.09a	1099.82b	74.16b	2.11b	67.06b	1.66a	827.50b	113.59a
E3	85.62b	4.22b	67.58b	4.67a	1239.95b	69.66b	2.44b	84.35b	1.69a	748.25b	123.55a
E4	77.53c	4.63b	68.42b	4.37b	1431.14a	64.66c	4.11a	68.97b	1.64a	741.01b	84.40b
E5	66.51d	4.11b	63.33b	4.43b	1321.38a	61.44c	3.33a	75.15b	1.62a	788.32b	85.20b
E6	58.68e	3.63b	30.51c	4.02b	868.09c	59.33c	2.33b	111.48a	1.64a	935.11a	102.65a

Means followed by the same lowercase letter in a column do not differ statistically from each other by Scott Knott's mean clustering test at 5% probability of error. Cultivation environments: E1 (Augusto Pestana – RS), E2 (Ijuí – RS), E3 (Catuípe – RS), E4 (Augusto Pestana – RS), E5 (Ijuí – RS), E6 (Catuípe – RS). * G Var (check): Variety

Table 2. Means of plant height (PH, cm), number of stem branches (NSB, unit.), 1000-grain weight (TGW, g) and grain yield (GY, kg ha^{-1}) of cultivar CISJU21 and control cultivars in tests of Value for Cultivation and Use (VCU), 2022 growing season and Cycle in the 2020, 2021 and 2022 growing seasons in six cultivation environments (Env)

	CULTIVARS											
Environ-ments	**CISJU 21**	**CDC Sorrel (check)**	**G Var (check)**	**CISJU 21**	**CDC Sorrel (check)**	**G Var (check)**	**CISJU 21**	**CDC Sorrel (check)**	**G Var (check)**	**CISJU 21**	**CDC Sorrel (check)**	**G Var (check)**
	PH			**NSB**			**TGW**			**GY**		
E1	70.40bB	81.33aA	76.20aA	4.75aA	5.82aA	4.00aA	4.90aA	3.18aB	3.55aB	945.52aA	837.94aA	792.38aA
E2	84.60aA	82.06aA	67.40aB	5.35aA	5.35aA	4.15aA	3.51aB	2.97aB	4.65aA	1167.50aA	954.67aB	788.61aB
E3	74.06bA	81.40aA	75.20aA	4.46aA	4.53aA	4.51aA	3.70aA	3.00aA	3.41aA	990.81aA	1010.49aA	1018.02aA
E4	76.20bA	76.93aA	70.73aA	2.60bA	3.33bA	2.40aA	3.93aA	3.92aA	2.79aA	1314.69aA	1202.84aA	1011.05aB
E5	80.00aA	80.76aA	75.53aA	2.73bA	3.26aA	3.70aA	4.45aA	4.12aA	3.42aA	1087.48aA	1040.29aA	1067.45aA
E6	70.60bA	76.60aA	70.58aA	2.20bB	3.00aB	4.71aA	4.50aA	4.04aA	3.44aA	1109.43aA	984.72aA	1188.57aA

Season	**CYCLE**					
	E1	E2	**E3**	**E4**	**E5**	**E6**
2020	173 bA	168 bB	157 bD	138 aE	134 cF	163 aC
2021	188 aA	177 aB	163 aC	162 aC	142 bD	135 bE
2022	173 bA	158 cC	143 cE	162 bB	147 aD	132 bF

Means followed by the same lowercase letter in a column and uppercase letter in a row, do not differ statistically from each other by Scott Knott's clustering test of means at 5% probability of error. Cultivation environments: E1 (Augusto Pestana – RS), E2 (Ijuí – RS), E3 (Catuípe – RS), E4 (Augusto Pestana – RS), E5 (Ijuí – RS), E6 (Catuípe – RS). G Var (check): Variety

grain yield (Dabalo et al. 2020), and grain oil content (Stanck et al. 2017).

With regard to the variable crop cycle (Table 2), the tested cultivars had similar performances. In 2020, the shortest cycle (134 days) was observed in environment 5 (sowing on June 15). The late sowing in environment 6 on July 1 induced early cycles in 2021 and 2022. A study of Dabalo et al. (2020), showed that late sowing of flax promoted a shorter cycle, due to the gradual increase in air temperature, promoting rapid growth and development.

To better explain the grain yield data, the Genotype + Genotype x Environment Interaction (GGE) method was used, in an attempt to explain, by biplot analysis, the higher grain yield of cultivar CISJU21, as well as its high phenotypic stability. In an analysis of the mean grain yield versus *or* together with stability (Figure 1), cultivar CISJU21 was clearly close to the desired agronomic ideotype, in view of the high grain yield and stability.

For the controls CDC Sorrel and the golden variety, a large deviation from the straight line was observed, due to the phenotypic instability in the field of these genotypes. When ranking the cultivars (Figure 2), cv. CISJU21 was found to have a higher grain yield than the commercial controls in the three study years and the six tested environments, with different sowing times.

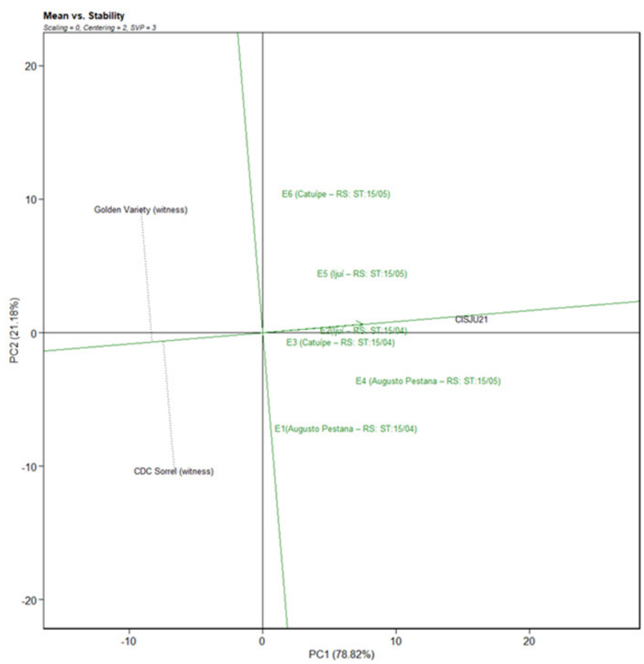

Figure 1. Genotype + Genotype x Environment Interaction (GGE) method, graph (mean grain yield x stability), cultivars CISJU21, CDC Sorrel (check) and a Golden variety (check), evaluated in six cultivation environments: E1 (Augusto Pestana – RS), E2 (Ijuí – RS), E3 (Catuípe – RS), E4 (Augusto Pestana – RS), E5 (Ijuí – RS), E6 (Catuípe – RS).

By isolating the effects of cv. CISJU21 (Figure 3), environments 3, 4 and 5 were found to be possibly the most suitable to produce maximized grain yields. In this way, cv. CISJU21 is indicated for cultivation in environments where seeding is recommended between May 15 and June 15, which was confirmed in 2020, 2021 and 2022.

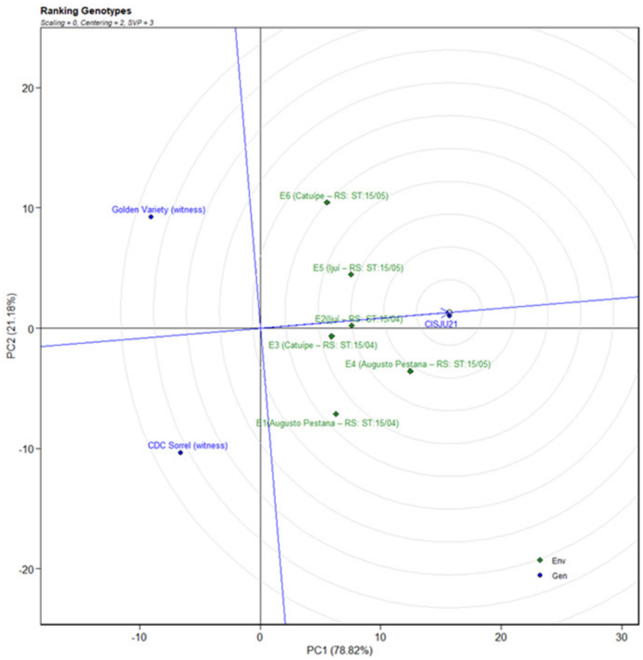

Figure 2. Genotype + Genotype x Environment Interaction (GGE) method, graph (ranking of cultivars), cultivars CISJU21, CDC Sorrel (check) and a Golden variety (check), evaluated in six cultivation environments: E1 (Augusto Pestana – RS), E2 (Ijuí – RS), E3 (Catuípe – RS), E4 (Augusto Pestana – RS), E5 (Ijuí – RS), E6 (Catuípe – RS).

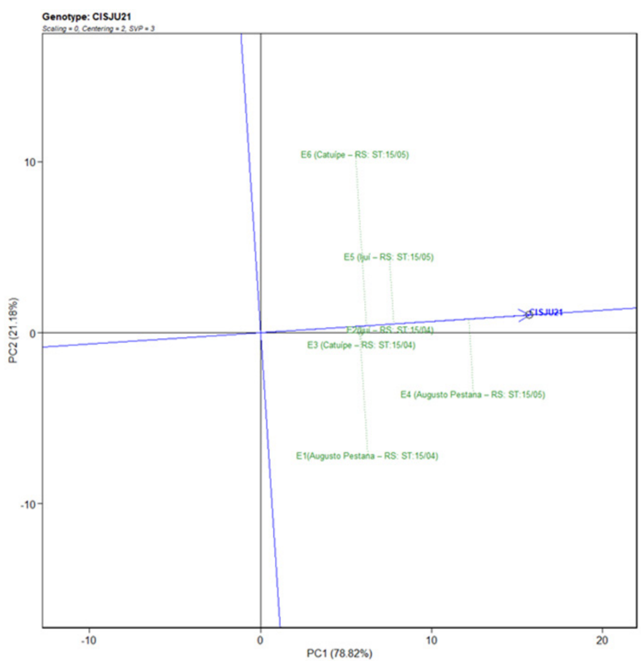

Figure 3. Genotype + Genotype x Environment Interaction (GGE) method, graph (isolated effect of CISJU21). cultivars CISJU21, CDC Sorrel (check) and a golden variety (check), evaluated in six cultivation environments: E1 (Augusto Pestana – RS), E2 (Ijuí – RS), E3 (Catuípe – RS), E4 (Augusto Pestana – RS), E5 (Ijuí – RS), E6 (Catuípe – RS).

OTHER RELEVANT TRAITS

The contrasting traits of cv. CISJU21 make it easily distinguishable under field conditions. Its phenotypic stability, resilience against the adversities of the cultivation environments, as well as aspects related to color uniformity and hues of the flowers can be named. The flowering period of the new cultivar has a shorter duration with consequently, greater homogeneity of the capsules with more regular sizes. Therefore, 1000-seed weight, length and width of the seeds of cultivar CDC Sorrel, used as commercial standard, are superior.

SEED PRODUCTION

The flax cultivar CISJU21 is intended for production of brown linseed and suited for human consumption, fresh or for oil extraction, was protected by the Ministry of Agriculture, Livestock and Supply (MAPA) on May 5,2022 (Process: N°21806.000054/ 2021). The procedures linked to the National Cultivar Register (RNC) are in progress, guided by the Innovation and Technology Agency of UNIJUÍ, which promotes and enhances interactions between the public and private sector. Thus, seed multiplication processes were initiated (for an initial availability of 920 kg).

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