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Mechanized Transplanting Improves Yield and Reduces *Pyricularia oryzae* Incidence of Paddies in Calasparra Rice of Origin in Spain

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Abstract: The rice variety Bomba is grown in Calasparra—a rice of origin in southeast Spain—resulting in a product with excellent cooking quality, although its profitability has declined in recent years due to low grain yields and susceptibility to rice blast disease (*Pyricularia oryzae* Cavara). An innovation project to test the efficacy of mechanized transplanting against traditional direct seed sowing was conducted in 2022 and 2023 at four locations for the first time. A lower plant density (67–82 plants m^{-2}) and shorter plants with higher leaf nitrogen content were observed in transplanted plots compared with seed sowing (130–137 plants m^{-2}) in the first year. The optimal climatic conditions for *P. oryzae* symptom appearance were determined as temperatures of 25–29 °C and a 50–77% relative humidity. The most-affected sowing plots presented 3–20% leaf area damage and a reduction in yield to values of 1.5 t ha^{-1} in the first year and 2.12 t ha^{-1} in the second year. In transplanted plots, there was generally less humidity at the plant level and therefore, disease incidence was low in both seasons. Grain yields did not significantly differ among the treatments studied; however, there were differences in the yield components of panicle density and the number of grains for panicles. Principal component analysis revealed two principal components that explained 81% of the variability. Variables related to yield contributed positively to the first component, while plant biomass variables contributed to the second component. Plant density, tiller density, and panicle density were found to be positively correlated ($r > 0.81$ ***). Overall, transplanting (frame of 30 × 15–18 cm^2) resulted in uniform crop growth with less rice blast disease, as well as higher grain yields (2.92–3.89 t ha^{-1}), in comparison with the average for the whole D.O. Calasparra (2.3–2.5 t ha^{-1}) in both seasons and a good percentage of whole grains at milling. This is novel knowledge which can be considered useful for farmers operating in the region.

Keywords: establishment method; rice blast disease; *Pyricularia oryzae*; panicle density; rice yield; protein content; nitrogen fertilization

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1. Introduction

Rice cultivation is a significant agricultural activity in the D.O. Calasparra region. Calasparra rice originates in an area of approximately 1000 ha in the municipalities of Calasparra and Moratalla (Murcia province) and Hellín (Albacete province) in southeast Spain. Low-input agricultural practises, together with ancient varieties, produce rice of a supreme quality that is recognized worldwide. In this region, paddies are cultivated in the mountains at 340–500 m above sea level using the continuous flow of water from the Segura and Mundo rivers, as opposed to the main Spanish rice-producing areas at sea level or close to river deltas (e.g., Valencia, Sevilla, and Delta del Ebro).

Two short-grain japonica rice varieties are grown in D.O. Calasparra, namely "Balilla × Sollana" and "Bomba". "Arroz Bomba" is a unique variety of Spanish rice that achieves an excellent cooking quality (due to a slightly higher amylose content of 23–26% with respect to other japonica varieties) [1], making it perfect for paellas and other Mediterranean rice dishes. It has never been bred and is of unknown origin, according to Carreres [1]; its purity has been maintained at Estación Arrocera de Sueca (Instituto Valenciano de Investigación Agraria) since 1929 through pedigree selection.

The agronomic characteristics of this variety are tall plants, low tillering, a short cycle, and low yield. In addition, "Bomba" is very susceptible to rice blast disease (*Pyricularia oryzae* Cavara).

The rice-producing sector in D.O. Calasparra started a project (GO ArrozInnova) in 2022 with the aim of testing a transplanting machine with the hope that this innovation might produce good rice stands and better grain yields. While direct seed sowing has been performed traditionally, some transplanting trials have been performed at Valencia, Sevilla, and Aragón in Spain, although at a small scale. García Floria [2] published related work in which the machine operated with rows 18 cm apart, planting 4–5 plants per lot within the rows. They concluded that by shortening the crop cycle, a reduction in water consumption and the use of agrochemicals and herbicides was obtained but particular attention to weed control is required at the early stages of crop development.

In this study, we aim to compare mechanized transplanting and traditional sowing methods. The specific research objectives include assessing the agronomic performance of both methods, evaluating the incidence of disease caused by *Pyricularia oryzae*, comparing grain yield, and analyzing the quality of rice using the "Bomba" variety in D.O. Calasparra. By achieving these objectives, we hope to contribute valuable insights into the effectiveness of mechanized transplanting compared to traditional sowing practises.

2. Material and Methods

2.1. Field Establishment, Treatments, and Locations

The scheme of the experiment is presented in Table 1. Trials were conducted at four distinct locations in 2022 (in parentheses, the municipality to which each one belongs is mentioned), which were Salmerón (Moratalla), Rotas (Calasparra), El Puerto (Calasparra), and Las Minas (Hellín), all of which are located within the D.O. Calasparra region. Fields at 3 locations (the same as above, except for El Puerto) were established in 2023. The farmers are mostly associated with the Virgen de la Esperanza cooperative, but El Puerto is associated with the Finca Pomabel S.L. The total area comprised 11.36 ha in 2022 and 3.89 ha in 2023. At each location, the field was divided into two parts, one for sowing and another for transplanting. Sowing plots in 2022 were subdivided into 2 parts, Sow–Std with standard N fertilization (doses between 75 and 135 kg N ha^{-1}) and Sow–Red with reduced N fertilization (50–90 kg N ha^{-1}). Transplanting plots in 2022 had standard fertilization and were also subdivided into 2 parts, Trans–18 (30×18 cm^2) and Trans–20 (30×20 cm^2), corresponding to different planting densities. Transplanting plots in 2023 (Trans–15) were established at a frame of 30×15 cm^2. In 2023, a standard fertilizer dose of 105 kg N ha^{-1} was applied to all sowing and transplanting plots. In all cases, fertilizer was applied in one go prior to crop establishment. The Bomba variety was established in all fields. In the sowing plots, 140 kg seed ha^{-1} was broadcast with a centrifuge fertilizer machine from

15 to 23 May 2022 and on 13 May 2023. The mechanized transplanting machine used was DAEDONG/KIOTI model S3–680, and it worked in rows which were 30 cm apart and was used to establish the crop in the corresponding plots on 6 to 9 June 2022 and 18 May 2023; previously, the plants had been in the nursery for 23 days. Control measures included standard irrigation practises and pest management protocols.

Table 1. Scheme of the experimental design.

Year	Reference	Establishment Method	Dose of Seed or Frame [1]	Nitrogen Dose (kg/ha) [1]	Establishment Dates
2022	Sow–Std	Sowing (control)	140 kg/ha	75–135	15–23 May 2022
	Sow–Red	Sowing	140 kg/ha	50–90	15–23 May 2022
	Trans–18	Mechanized transplanting	30 cm × 18 cm	75–135	6–9 June 2022
	Trans–20	Mechanized transplanting	30 cm × 20 cm	75–135	6–9 June 2022
2023	Sow–Std	Sowing (control)	140 kg/ha	105	13 May 2023
	Trans–15	Mechanized transplanting	30 cm × 15 cm	105	18 May 2023

[1] Frame and nitrogen dose in 2023 were established based on the results of 2022.

2.2. Variables Studied

The rice crop was monitored throughout the season each year. The variables studied were as follows:

- Plant density (number of plants m^{-2}) at 27–32 days after transplanting or sowing with a sampling area of 3×1 m^2;
- Tiller density (number of tillers m^{-2}) at the maximum tillering stage;
- Plant height (cm);
- Leaf N content (%) according to the Dumas method, with leaves sampled at first panicle appearance. Each sample consisted of 50 leaves (leaf Y = youngest and unfolded) from different plants;
- Panicle density (number of panicles m^{-2});
- 1000 seed weight (g);
- Number of grains per panicle.

For each treatment and location plot, three repetitions were collected for each variable (multiple measurements). Each repetition was derived from a single randomly selected site within each plot. Plant height was measured using 10 plants within each combination.

2.3. Pyricularia oryzae Disease Incidence

Climatic conditions at the plant level in each plot were monitored using data loggers (Hobo Onset MX1101), which registered temperature (T) (°C) and relative humidity (RH) (%) at hourly intervals.

Petri dishes were located in each plot for fungal conidia captures every week during the first year. The presence of rice blast disease (*P. oryzae*) in plants was also monitored every week during both years. Leaf damage severity was estimated with a 0.1–50% area damage scale, for which eight leaves of ten plants were measured for each treatment and location combination. The percentage of infested necks, knots, and panicles (with symptoms) was also calculated every week in eight of these items from ten plants for each treatment and location combination. Plants with *P. oryzae* symptoms were taken to the laboratory to isolate the fungus directly from the plants or after wet chambers (25–26 °C for 3–5 days) of the material. Species were identified by microscopic preparations and observations of conidia characteristics.

2.4. Grain Yield

Harvesting took place on 22–29 September 2022 and 12–30 September 2023 using a grain harvester in each plot separately, such that we were able to obtain real production data. In addition, 3 samples of 1 m^2 were harvested by hand, derived from 3 randomly selected sites in plots corresponding to treatment and location combinations, prior to the harvester work. Grain yield is expressed as t paddy ha^{-1}. Industrial yield (%) and whole grain industrial yield (%) were estimated using a laboratory rice milling machine fed with 200–500 g per sample. Industrial yield refers to the total percentage of rice obtained after milling, while whole grain industrial yield indicates the percentage of whole, unbroken grains, excluding any broken grains.

2.5. Rice Quality

Analysis was performed on white polished rice from the 2022 harvest. Dry matter content, ashes, and dietary fibre were determined according to the weight difference after drying the samples at 100 °C (24 h) and 555 °C (16 h) followed by hydrolysis. Sodium and inorganic arsenic were quantified via ICP-MS. Amylose content was quantified using spectrophotometry (620 nm). Protein content was measured using the Kjeldahl method on rice of the two harvests (2022 and 2023). Lipids were measured through Soxhlet extraction. Finally, carbohydrates were calculated using the following formula: 100 − (total lipids + dietary fibre + protein + ashes + dry matter).

2.6. Nitrogen Uptake of the Rice Crop

Whole aerial rice plant biomass was sampled from three sites (0.25 or 0.5 m^2) per plot, corresponding to treatment and location combinations, harvested at three times during the crop cycle in 2023. The first was on 15 June (tillering), the second on 26 July (panicle emergence), and the third on 5 September (end of grain ripening). Fresh and dry weight (g) were obtained for each sample after drying in a stove at 65 °C for 24 h (until constant weight). Nitrogen content (%) was quantified using the Dumas method. Nitrogen uptake is expressed as kg N ha^{-1}.

2.7. Statistical Analysis

Agronomic and yield variables were tested by two-way ANOVA with treatment and location as factors. In 2022, analyses were performed, on the one hand, for an "establishment method" involving mechanized transplanting (Trans–18 and Trans–20) and sowing (Sow–Std) and on the other, for "N fertilisation", involving reduced fertilization (Sow–Red) versus standard fertilization (Sow–Std). In 2023, analyses were performed just for the "establishment method". We used ANOVA for its robustness in comparing multiple groups due to the variability in data. Where significant differences were present ($p \leq 0.05$), pairwise comparisons between the treatments and between locations were conducted using the least significant difference (LSD) test.

The number of *Alternaria* sp. conidia captured with Petri dishes in the paddy fields was transformed by $Log_{10}(x + 1)$ prior to statistical analysis. The significance of the treatment factor within each location and date was tested through one-way ANOVA and when significant ($p \leq 0.05$), a pairwise comparison was performed using the LSD test.

Disease (*P. oryzae*) severity in leaves was compared within locations for different dates using a Kruskal-Wallis non-parametric test, and Dunn's test was performed for a pairwise comparison of the means. The treatments of year 2022 were considered one factor with four levels for comparisons.

The means of the nutritional and mineral composition of rice, according to the established method in different locations, were compared with one-way ANOVA; if the difference was significant ($p \leq 0.05$), Tukey's post hoc test was performed for pairwise comparisons.

Multivariate analysis was performed with data from the 2022 season. Pearson's product moment correlation coefficient and significance test of variable response were calculated using the R package stats [3]. The plot for visualization of the correlation matrix was made with the corrplot package with the option 'hclust' for the hierarchical clustering order [4]. Principal component analysis and graphs were carried out with data centred and scaled using the R packages FactoMineR [5] and factoextra [6], respectively. The correlation between response variables and the principal component analysis were conducted according to the mean value of each treatment–location combination.

3. Results

3.1. Agronomic Performance

In Tables 2 and 3, summaries of the results for the variables studied are provided. Plant establishment varied according to treatment and location. Higher plant densities were obtained with direct seed sowing (130–137 plants m^{-2}) than transplanting (67–82 plants m^{-2}) in 2022, but the opposite was observed in 2023, with 126–160 plants m^{-2} by sowing and 174–217 plants m^{-2} by transplanting. Figure 1 shows the rice transplanting machine. Overall, rice plants provided good crop coverage over time, regardless of the establishment method. The crop cycle was shortened from 135 days (sowing) to 110 days (transplanting) due to a reduction in the vegetative period during the first year (2022). The first panicles appeared on 27–31 July. On average, plant height was 119.87–137.1 cm, with statistically significant differences among treatments (see Tables 2 and 3). Transplanting resulted in shorter plants being less prone to lodging. In addition, more leaf N content was found in rice from transplant plots (2.62–2.75%) compared to sowing (2.20–2.39%) in 2022, while the difference was not significant in 2023.

Table 2. Agronomic and yield variables of a rice crop (variety "Bomba") grown at D.O. Calasparra (Spain) in 2022 [1].

	Plant Density (m^{-2})	Tiller Density (m^{-2})	Plant Height (cm)	Leaf N Content (%)	Panicle Density (m^{-2})	No. Grains/ Panicle	1000 Grain Weight (g)	Filled Grains (%)	Grain Yield (t ha^{-1})	Industrial Yield (%)	Whole Grains Industrial Yield (%)
Means and pairwise comparisons of establishment method: mechanized transplanting (Trans–18 and Trans–20) and sowing (Sow–Std) [2]											
Trans–18	82.22 B	220.67 B	118.3 A	2.75 A	182.1 B	85.49 A	25.97 A	96.07 AB	3.89 A	74.75 A	67.68 A
Trans–20	67.08 B	189.33 B	110.6 B	2.62 A	153.8 B	76.80 A	24.14 A	95.34 B	2.89 B	70.13 B	63.51 A
Sow–Std	137.08 A	279.17 A	122.1 A	2.20 B	220.9 A	64.47 B	26.39 A	96.69 A	3.48 AB	68.64 B	62.90 A
F (d.f. = 2; 27) [3]	28.973 ***	18.193 ***	12.844 ***	15.342 ***	15.344 ***	7.203 **	1.366	2.702	1.502	7.463 **	5.098 *
Means and pairwise comparisons of N fertilizations: reduced fertilization (Sow–Red) vs. standard fertilization (Sow–Std) [2]											
Sow–Red	130.42 A	319.67 A	128.1 A	2.39 A	266.0 A	63.70 A	25.30 A	94.03 A	3.66 A	68.92 A	63.33 A
Sow–Std	137.08 A	279.17 B	122.1 B	2.20 B	220.9 B	64.47 A	26.39 A	96.69 A	3.48 A	68.64 A	62.90 A
F (d.f. = 1; 19) [4]	0.478	4.496 *	8.242 **	6.088 *	7.415 *	0.034	2.029	3.774	0.612	0.579	0.340
Global mean	105.7	254.31	119.87	2.47	207.29	71.76	25.41	95.5	3.45	70.33	64.13

[1] F statistic of the ANOVA. *** $p < 0.001$, ** $0.01 > p > 0.001$, * $0.05 > p > 0.01$. Different letters indicate statistically significant differences at $p \leq 0.05$ by LSD. [2] See Table 1 for the treatments. [3] Plant height variable d.f. = 2; 104. [4] Plant height variable d.f. = 1; 75.

Table 3. Agronomic and yield variables of a rice crop (variety "Bomba") grown at D.O. Calasparra (Spain) in 2023 [1].

	Plant Density (m^{-2})	Tiller Density (m^{-2})	Plant Height (cm)	Leaf N Content (%)	Panicle Density (m^{-2})	No. Grains/ Panicle	1000 Grain Weight (g)	Filled Grains (%)	Grain Yield (t ha^{-1})	Industrial Yield (%)	Whole Grains Industrial Yield (%)
Means and pairwise comparisons of establishment method: mechanized transplanting (Trans–15) and sowing (Sow–Std) [2]											
Trans–15	217.2 A	404.0 A	133.4 B	2.32 A	196.7 A	96.7 A	23.4 A	98.62 B	2.92 A	71.7 A	60.2 A
Sow–Std	148.3 B	353.2 B	140.7 A	2.42 A	183.1 A	100. 9 A	19.9 B	97.49 A	3.09 A	72.3 A	63.2 A
F (d.f. = 1; 14) [3]	15.896 **	5.459 *	18.663 ***	0.886	0.745	0.811	6.876 *	13.807 ***	0.354	0.847	3.845
Global mean	1182.8	378.6	137.1	2.37	189.9	98.8	21.7	98.96	3.01	72	61.7

[1] F statistic of the ANOVA. *** $p < 0.001$, ** $0.01 > p > 0.001$, * $0.05 > p > 0.01$. Different letters indicate statistically significant differences at $p \leq 0.05$ by LSD. [2] See Table 1 for the treatments. [3] Plant height variable d.f. = 1; 56.

Figure 1. Rice transplanting machine. On the sides of the machine are nursery trays with young rice plants ready for transplantation. At the back, an automatic transplanting mechanism picks up the seedlings with mechanical forks and carefully places them into the soil.

3.2. *Pyricularia oryzae* Incidence

The fungus most frequently found during July and August was *Alternaria* sp. (Table S1). Colonies were found on the PDA plates of the year 2022. The highest number of conidia was counted in the Sow–Std and Sow–Red treatments, corresponding to the sowing plots. In the Trans–18 and Trans–20 treatments of the transplant plots, the associated numbers were lower. The possible reason for this difference is that the more plants there are, the higher the humidity, which is favourable for fungal propagation. Notwithstanding, *Alternaria* sp. does not cause any disease in rice; therefore, it was considered a saprophyte.

Rice blast disease (*P. oryzae*) was detected in the experimental fields during 2022 and 2023. The symptoms in leaves are shown in Figure 2. The initial symptoms manifest as white to grey-green lesions or spots bordered by dark green edges, whilst older lesions on the leaves are elliptical, exhibiting whitish to grey centres with red to brownish or necrotic borders. The presence of the disease was confirmed through the isolation of conidia from wet chambers of infested plant material (Tables S2 and S3). During 2022 (see Tables S2 and 4), the first infections appeared in Rotas in mid-July. During 2023 (see Tables S3 and 5), the disease appeared on the third of July in the Rotas location, with higher severity in the transplanted plot due to higher plant densities. Notably, fungicide spraying (azoxystrobin and difeconazol) of the crop was effective. Infections appeared in all other locations but with less incidence than the prior year. In all cases and up to the harvesting time, lodging was seen.

Figure 2. *Pyricularia oryzae* symptoms in leaves of rice plants.

Table 4. Disease severity in plant leaves: percentage of leaf area with *Pyricularia oryzae* damage (scale 0.1–50%) in different treatments [1,2] in 2022.

	Sow–Std	Sow–Red	Trans–18	Trans–20
		Location: Las Minas		
21 July	0 a	0 a	0.10 b	0.02 ab
28 July	0 a	0 a	0.16 b	0.03 a
3 August	0 a	0 a	0.36 b	0.03 a
11 August	0 a	0 a	0.26 b	0.01 a
17 August	0 a	0 a	0.22 b	0 a
24 August	0 a	0 a	0.21 b	0.02 a
		Location: Rotas		
14 July	0.375 b	0 a	0 a	0 a
18 July	0.88 b	0 a	0 a	0 a
27 July	0.41 b	0.02 a	0 a	0 a
4 August	2.01 b	0.25 a	0 a	0 a
9 August	2.63 b	0.73 a	0 a	0 a

Table 4. *Cont.*

	Sow–Std	Sow–Red	Trans–18	Trans–20
22 August	1.96 c	1.125 b	0 a	0.08 a
29 August	2.47 b	1.9875 b	0 a	0.08 a

[1] See Table 1 for the treatments. [2] Different letters within a row indicate statistically significant differences at $p \leq 0.05$ among the treatments by Dunn's test after Kruskal-Wallis non-parametric test significance.

Table 5. Disease severity in plant leaves: percentage of leaf area with *Pyricularia oryzae* damage (scale 0.1–50%) under different treatments [1,2] in 2023.

	Sow–Std	Trans–15
Location: Las Minas		
12 July	0.16 a	0.16 a
17 July	0.20 a	0.18 a
26 July	1.71 a	0.73 a
3 August	2.06 b	0.67 a
10 August	2.30 b	0.91 a
17 August	4.77 a	2.07 a
23 August	5.02 a	2.88 a
29 August	4.66 a	2.82 a
Location: Rotas		
6 July	0.44 a	1.53 b
12 July	0.69 a	1.58 b
17 July	1.19 a	3.29 b
30 July	0.31 a	0.90 a
3 August	0.33 a	0.84 a
10 August	0.70 a	0.55 a
17 August	0.31 a	0.21 a
23 August	0.46 a	0.25 a
29 August	0.28 a	0.16 a
5 Sep	0.27 a	0.22 a
13 Sep	1.13 a	0.87 a
Location: Salmerón		
12 July	0.07 a	0.11 a
17 July	0.05 a	0.12 a
26 July	0.17 a	0.13 a
3 August	0.17 a	0.42 a
10 August	0.43 a	0.65 a
17 August	0.22 a	0.72 a
23 August	1.05 a	0.81 a
29 August	2.25 a	1.71 a
5 September	2.22 a	1.23 a
13 September	2.75 a	1.17 a

[1] See Table 1 for the treatments. [2] Different letters within a row indicate statistically significant differences at $p \leq 0.05$ among the treatments by Dunn's test after Kruskal-Wallis non-parametric test significance.

Data loggers located in each plot allowed us to register average temperatures of 25–29 °C and an RH of 50–77% in the plots during the days close to fungal disease detection, indicating the optimal values in our environment. The transplanted plots, due to lower plant densities during 2022, registered lower values of RH (50–57%), explaining the lack or reduction in disease incidence in 2022. However, in 2023, the transplant plots had too many plants at some locations, creating humid conditions suitable for the disease.

In Table 4 (year 2022), the disease severity (expressed as % of leaf area damaged) results show that the sowing plots at the Rotas location were the most affected, up to 20% at the most affected spots. From Table 5 (year 2023), we can see a lower blast incidence for this season (less than 5% leaf area damage) overall. With crop development, the symptoms propagated to the knots, necks, and panicles (Tables 6 and 7). By 9 August 2022, over 27.5% of the knots were damaged at Rotas in the Sow–Std plot. In the Trans–20 plots, some symptoms appeared at the end of the season, usually with low incidence in 2022 (Table 6). By 30 July 2023, over 11.25% of the knots were damaged at Rotas in the transplant plot but at harvesting (13 September), the disease incidence was again more evident in sowing plots (over 20% of the knots damaged) in 2023 (Table 7).

Table 6. Percentage of knots, necks, and panicles damaged by *Pyricularia oryzae* in rice plants (location: Rotas) under different treatments [1] in 2022.

	Sow–Std			Sow–Red			Trans–18			Trans–20		
	% knots	% necks	% panicles	% knots	% necks	% panicles	% knots	% necks	% panicles	% knots	% necks	% panicles
14 July	0	0	0	0	0	0	0	0	0	0	0	0
18 July	0	0	0	0	0	0	0	0	0	0	0	0
27 July	0	0	0	0	0	0	0	0	0	0	0	0
4 August	0	0	0	0	0	0	0	0	0	0	0	0
9 August	27.5	5	0	15	1.25	0	0	0	0	0	0	0
16 August	22.5	6.25	0	7.5	3.75	0	0	0	0	1.25	0	0
22 August	26.25	13.75	8.75	11.25	7.5	3.75	0	0	0	6.25	3.75	0
29 August	26.25	13.75	10	16.25	11.25	7.5	0	0	0	5	3.75	0

[1] See Table 1 for the treatments.

Table 7. Percentage of knots, necks, and panicles damaged by *Pyricularia oryzae* in rice plants (location: Rotas) under different treatments [1] in 2023.

	Sow–Std			Trans–15		
	% knots	% necks	% panicles	% knots	% necks	% panicles
17 July	0	0	0	25	1.25	0
26 July	0	0	0	7.5	2.5	0
30 July	6.25	1.25	0	11.25	1.25	0
3 August	2.5	0	0	0	0	0
10 August	1.25	1.25	0	3.75	1.25	1.25
17 August	2.5	5	3.75	5	0	3.75
23 August	7.5	6.25	8.75	5	0	0
29 August	5	2.5	7.5	6.25	1.25	2.5
5 September	5	1.25	5	5	2.5	3.75
13 September	20	20	20	3.75	3.75	5

[1] See Table 1 for the treatments.

Mechanized transplanting led to a 20% reduction in disease incidence compared to traditional methods (Table 7).

3.3. Grain Yield and Yield Components

Rice harvesting took place on 20–29 September 2022 and 12–18 September 2023. In 2022, the ripening stage was optimal in the sowing plots. However, in the transplanted plots, the rice had not yet fully ripened, but we decided to harvest everything at the same time due to the availability of the grain harvester. The transplanted plants had spent 23 days in the nursery, and transplantation occurred 14–25 days after sowing (about 20 days later). The age of the transplanted and sown plants was approximately the same, but it is likely that post-transplant stress caused this slight delay in maturation.

In contrast, in 2023, the situation was reversed. The transplant took place just 5 days after sowing, and the transplanted plants had also spent 23 days in the nursery. This made the transplanted plants 18 days older than the sown ones, which allowed them to mature more effectively.

In Tables 2 and 3, a summary of the grain yield results is provided. There were no statistically significant differences among the treatments, and the Trans–18 plots gave the greatest value of 3.89 t ha^{-1}. Yields in 2023 were on average lower than the year before, again without differences among the treatments.

In Rotas, transplanted plants performed much better than sown plants in 2022, as the incidence of *P. oryzae* caused a reduction in yield to 1.5 t ha^{-1}.

Yield components were also studied (Table 2). There were statistically significant differences among treatments for panicle density [F (2; 27) = 15.3 ***] and the number of grains per panicle [F (2; 27) = 7.203 **] in 2022, while there were no differences in 2023 (Table 3). Sown plots had more panicles m^{-2} due to greater numbers of plants established in 2022. Therefore, to increase yields in transplanted plots, a strategy to improve the number of established plants must be followed. Thus far, we have seen that the plants counterbalance lower panicle densities by increasing the number of grains per panicle; however, this is not enough to compensate for the lower number of panicles.

3.4. Rice Quality and Industrial Yield

Bomba had an average industrial yield of 70.33% in 2022. Grains from transplanted plots were uniform and of the best quality (Table 2). Industrial yield in 2023 was 72% on average without differences between the treatments (Table 3). Concerning the location, the differences found in this variable were due to rice blast disease; for instance, the industrial yields in Rotas were much lower (61.9%) due to the failure of grain filling in 2022. Whole grain industrial yield was 64.13% in 2022 on average, following the same pattern of results as explained before. As for the 2023 data, an average of 61.7% was obtained (Table 3); again, whole grain industrial yield in Las Minas had a low value of 58.1%, possibly due to the incidence of blast disease.

Table S4 presents data on the analyzed nutritional and cooking quality parameters. The amylose content in the grain ranged from 18.8 to 18.85%. There was hardly any difference in results among the factors studied, and the establishment method used (sowing or transplanting) did not correlate with the quality, only significantly ($p \leq 0.05$) affecting the protein content in the grain (Table 8) in both seasons. Rice samples from transplanted plants showed a significant increase in protein (content of 7.3–8.3%) compared to directly sown plants (with a content of 6.7–8%) in all locations tested in 2022. This increase was similar in all the plots studied. Rice samples from transplanted plants in 2023 showed a significant increase in protein (content 8.4–9%) compared to sowing plants (content 7.8–7.9%) at two locations. While rice is poor in nitrogenous substances and the protein fraction of rice is approximately 7–8%, this value can change depending on the variety and environmental conditions of production. It is possible that the lower plant densities or different establishment framework in transplant plots allowed for a better absorption of N and therefore elevated protein synthesis in the plant.

Table 8. Protein content (g 100 g^{-1}) in white rice from experimental plots in 2022 and 2023 [1].

		2022	2023
El Puerto	Sowing	6.7 a	-
	Transplant	7.3 b	-
Las Minas	Sowing	7.1 a	8.2 ± 0.3
	Transplant	8.3 b	8.4 ± 0.1
Rotas	Sowing	8.0 a	7.8 ± 0.2 a
	Transplant	8.3 b	9.0 ± 0.3 b
Salmerón	Sowing	6.7 a	7.9 ± 0.1 a
	Transplant	8.1 b	8.4 ± 0.2 b

[1] Mean ± standard deviation (n = 6). Tukey's test for mean comparison. Different letters within a column (year) and location indicate statistically significant differences at $p \leq 0.05$.

3.5. Nitrogen Uptake of the Rice Crop

Biomass production increased during the crop cycle. There was a statistically significant difference [F (1; 14) = 67.79 ***] between plant growth in sowing (22.5 g m^{-2} dry matter) and transplant plots (53.7 g m^{-2} dry matter) during tillering and up to panicle emergence in 2023. This occurred because the nursery plants used in transplant plots had 23 days of development in advance. However, plants in the sowing plots grew faster (485.8 vs. 348 g m^{-2} dry matter) in the end (sampling date: 5 September 2023), resulting in similar crop coverage.

In Figure 3, a graphical display of the nutrient absorption values is shown. N uptake increases along the plant cycle. Biomass from transplant plots presented greater values (kg N ha^{-1}) than that from sowing plots during the vegetative and reproductive periods of the crop, whilst sowing plots absorbed more N towards the end of the cycle (grain ripening) at two locations (Salmerón and Las Minas). At the Rotas location, throughout the whole season, higher N absorption was observed in plants from transplant plots. The maximum N uptake was 71 kg N ha^{-1} and therefore, the amount of fertilizer applied, 105 kg N ha^{-1}, seems sufficient to cover the requirements of the rice variety Bomba in Calasparra.

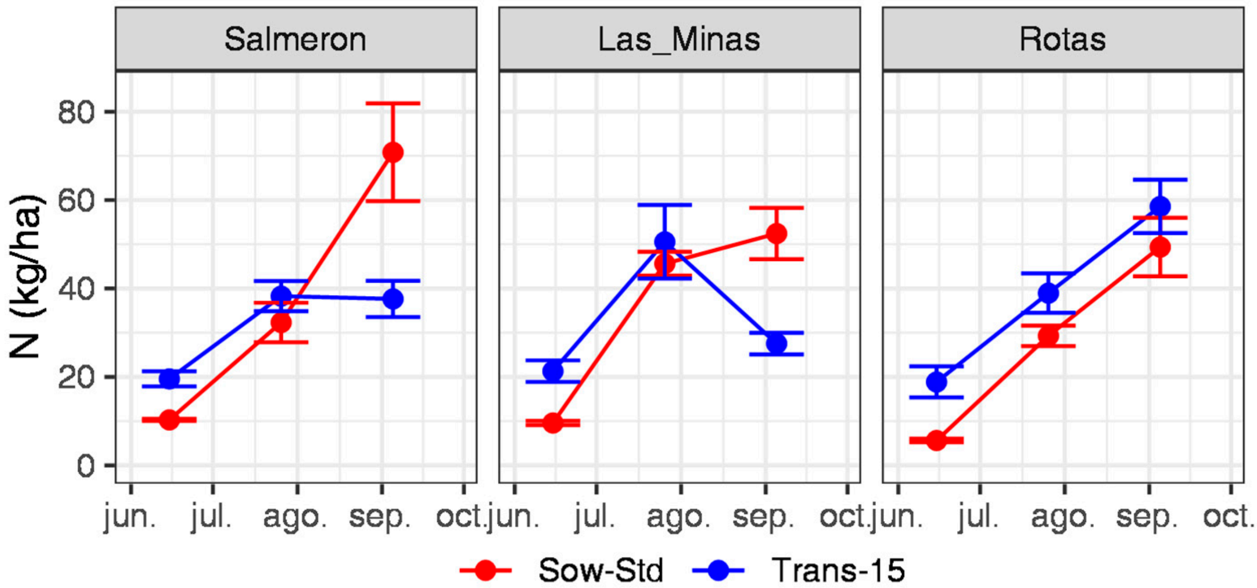

Figure 3. Nitrogen uptake in rice crop biomass throughout the season at three locations, according to the establishment method in 2023, with a fertilizer dose of 105 kg N ha^{-1}. Sow–Std = sowing;

Trans–15 = mechanized transplanting. Each point represents the mean, and the error bars indicate the standard error of the mean (SEM) calculated from $n = 3$ samples.

3.6. Correlation and Principal Component Analysis

In Figure S1, the correlation analysis among variables is depicted. Data on coefficient values and probabilities are detailed in full in Table S5. Figure 4 shows a representation of the principal component (PC) analysis. In Table S6, the coordinates of PCs are included in full. PC1 and PC2 accounted for 81% of the variability; therefore, only these two components were used for the graphic.

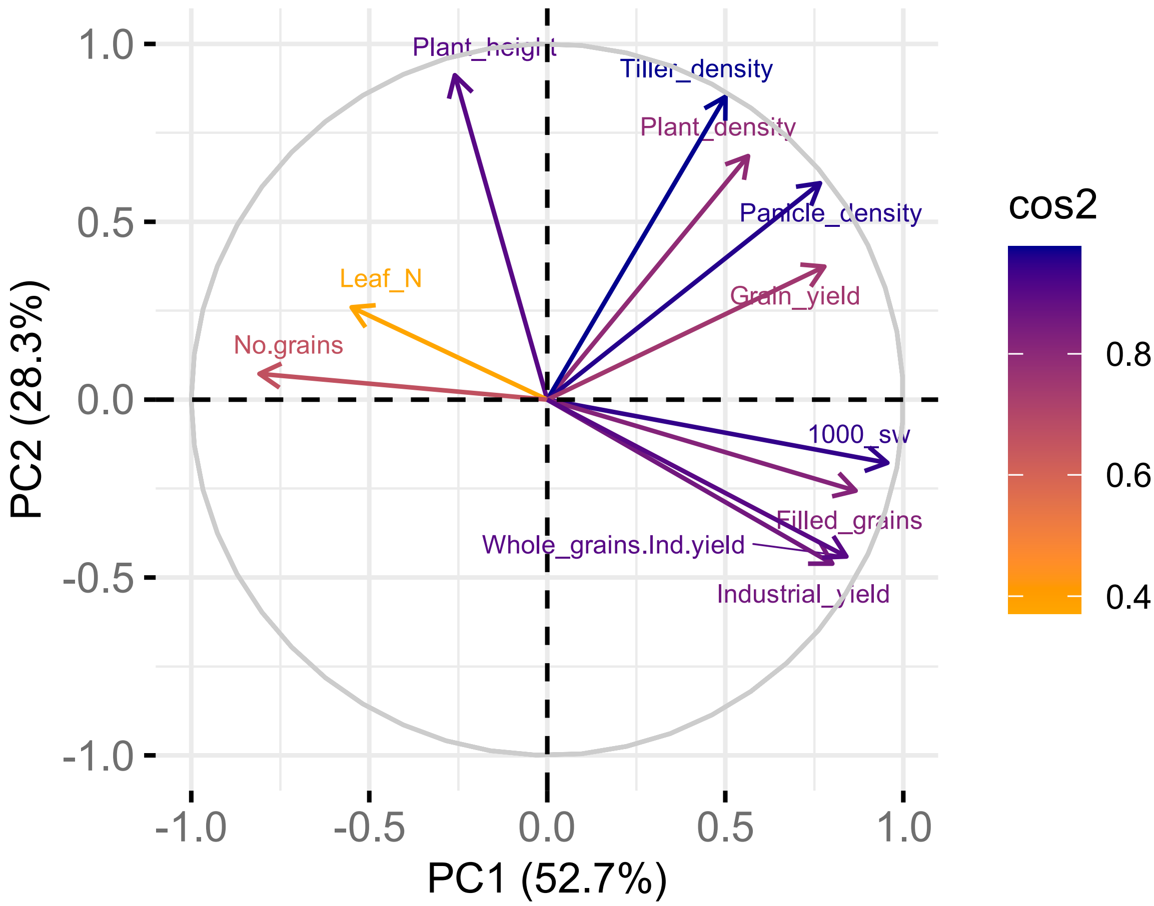

Figure 4. Principal component analysis (PCA) of agronomic and yield traits in a rice crop, based on 2022 data (see Table 2). Variables contributing positively to PC1 (which explains 52.7% of the total variance) include yield-related traits such as 1000 grain weight, filled grains, whole grain industrial yield, industrial yield, and grain yield. In contrast, PC1 is negatively correlated with the number of grains per panicle and leaf nitrogen content. Variables contributing positively to PC2 (which explains 28.3% of the total variance) are plant biomass traits such as plant height, tiller density, plant density, and panicle density.

There was a correlation (r = 0.817 ***) between leaf N content and the number of grains per panicle. This is due to transplanted plants having a higher N content, which was correlated with fewer panicles m^{-2} and with panicles with a greater number of grains (r = −0.612 *). From Figure 4, we can see that PC1 is negatively correlated with the number of grains per panicle and leaf N content, although this variable is more relevant in PC3 (see Table S6).

Plant density was positively correlated with tiller density (r = 0.872 ***) and panicle density (r = 0.815 ***), while tiller density was positively correlated with panicle density (r = 0.897 ***). In Figure 4, we can see that the variables contributing strongly to PC2 include plant height, tiller density, and other plant biomass variables (e.g., plant density or panicle density).

The two main components of grain yield were panicle density (r = 0.813 ***) and 1000 SW (r = 0.763 **), followed to a lesser extent by tiller density (r = 0.687 **). In the PC plot (Figure 4), we can see that variables contributing positively to PC1 are a complete set of yield-related variables, including grain yield, 1000 SW, panicle density, filled grains, industrial yield, and whole grain industrial yield.

Industrial yield is related to the percentage of filled grains (r = 0.807 ***) and 1000 SW (r = 0.9 ***), as the higher the rice quality, the higher the milling yield. As expected, this variable was also correlated with whole grain industrial yield (r = 0.955 ***). There was a negative correlation between 1000 SW and the number of grains per panicle (r = −0.676 **) and so, fewer grains resulted in heavier seeds. In addition, if the number of grains was too high, there were fewer filled grains (r = −0.714 **) in a panicle; this result is also related to *P. oryzae* incidence, as the diseased plants produced long panicles with many empty grains.

4. Discussion

4.1. Establisment Method

The mechanized transplanting trial of rice in Calasparra in Spain has provided good results. Weeds were found to be a drawback in transplanted plots, though, as the crop took more time to cover the soil than in sowing plots. Therefore, competition between the plants and weeds occurred. As such, a strategy for weed control (pre-sowing and pre-emergence) must be developed if transplanting is introduced at a large scale in D.O. Calasparra.

In other parts of the world, the production systems and weather conditions are different, but innovations are still needed. For instance, in the Ganges River, rice is usually established manually through puddling transplanting, and experiments have been conducted to test mechanized dry seeding, providing the advantages [7] of a 9% reduction in labour costs, a reduction in the amount of irrigation water needed, and the timely establishment of the paddy and succeeding crops; however, seeding increased the cost of seeds and fertilizer.

4.2. Nitrogen Fertilization

According to Aguilar [8], the critical N content in leaves during tillering is 2.8%; therefore, in our plots, the level of this nutrient seemed to be low.

Plants from transplanted plots in our experimental fields had more nitrogen in the leaf and more protein in the grain. These findings suggest that mechanized transplanting could be beneficial in other regions with similar agronomic conditions. In addition, N uptake also increased with the plant cycle. According to Tinarelli [9], protein content is influenced by plant density, the amount of nitrogen fertilizer, and the intensity of solar radiation during grain development. In previous studies [10], we obtained 7.8–8.9% protein content in Bomba rice grown in D.O. Calasparra, which is higher in comparison with another variety (Balilla × Sollana) also grown in the area. It is possible that better nutritional quality and superior cooking quality [11] are characteristics of the Bomba variety.

Thus, an increase in nitrogen fertilization can increase the percentage of some amino acids, consequently increasing the protein content [12]. In our study, the greater separation between plants due to establishment using the transplanting machine improved nutrient uptake (including nitrogen), positively affecting protein synthesis and storage.

He et al. [13] noted that a high N application rate results in high grain yields but also favours lodging, pest, and disease risks in the Yangtze River in China. In addition, increasing the N application rate seemed to decrease the nutritional quality through affecting the amylose and protein contents in medium indica hybrid cultivars. The combination of good quality and high yields corresponded to fertilizer rates of 130–140 kg N ha^{-1}.

4.3. Pyricularia oryzae Incidence

Given the presence of inoculum, the environmental conditions suitable for rice blast disease in Calasparra (Spain) are temperatures of 25–29 °C and a relative humidity of 50–77% at the plant level; usually, these conditions occur from mid-July onwards. We recommend farmers to search for plant symptoms and treat with fungicides as soon as the conditions are reached. Transplanted plots, due to their better aeration and less RH, were less favourable for the spread of disease, although the maintenance of such an advantage is unclear if dense plant stands were to be established. In other rice production areas in Spain—for example, in Delta del Ebro—earlier sowings in the season have prevented the coincidence of susceptible stages of the crop with the optimal climatic conditions for the fungus. However, based on our results, we recommend farmers to adopt mechanical transplanting to reduce disease incidence and stabilize yields, thus enhancing profitability.

Osca et al. [14] published that fertilizer plays a role in *P. oryzae* incidence (in particular, excess N favours disease severity in leaves and panicles) in years less prone to the disease. On the other hand, fertilizer is not as important in years prone to the disease, and fungicidal treatments are the best way to control rice blast incidence. The best yields were obtained with 110 kg N ha^{-1}. Sendra [15] published that the Bomba variety is not efficient in N absorption, such that excess N fertilizer causes lodging (particularly for tall varieties such as this one) and favours *P. oryzae* disease. From our work, a fertilizer dose of 105 kg N ha^{-1} seems reasonable. In Spain, authorized active ingredients for *P. oryzae* are azoxystrobin, pyraclostrobin, trifloxistrobin, difeconazol, sulphur, and *Bacillus subtilis*. The reduction in the number of active ingredients might lead to increased difficulty controlling the disease in the future. The best recommendation would be fungicide spraying as soon as the critical climatic conditions (in terms of temperature and relative humidity) are reached, together with monitoring for symptoms of the disease in the plants.

4.4. Nutritional and Cooking Quality of Rice

In general, the values obtained for the nutritional composition, macronutrients, and minerals in rice in our study were similar to those previously published for the Bomba variety [16,17]. However, the amylose percentages were lower than those described in the literature, with values ranging between 19.5% and 23.0% for this variety [18,19]. In this regard, it has been described that amylose content in rice is affected by both ambient and air temperatures, with a decrease in amylose content observed as these parameters increase [20,21]. Therefore, the increase in average temperatures in southeastern Spain over the last twenty years may be negatively affecting the amylose content of rice.

Concerning rice quality, in the literature [22], a report considering a group of genotypes (both indica and japonica rice varieties included) showed a range in protein content from 7 to 10.8% and a positive correlation with macronutrients (N, P, K, Mg) and micronutrients (Fe, Zn) in the grain. The amylose content was in the range of 15.53–21.53% (with the highest value observed in a japonica variety).

4.5. Yield and the Challenge of Sustainable Rice Production with Less Water

Increasing panicles m^{-2} will likely increase grain yields. One way to accomplish this is by increasing plant density, so long as the optimal range of 130–220 plants m^{-2} is not overcome. Panicles m^{-2} is the yield component which is more strongly influenced by the amount of fertilizer used [23]. Carreres [1] noted that the yield potential of the Bomba variety is 4.5 t paddy ha^{-1}. In D.O. Calasparra, rice yields tend to be lower due to the use of a low-input production system. For instance, on average, 2.3–2.5 t ha^{-1} was obtained for the Bomba variety, taking into account all the farmers in the region. However, our experimental fields showed that transplanted yields could likely reach 3.01–3.45 t ha^{-1}. A potential limitation of the study is the short duration of two years. Future research should consider longer-term studies to validate these findings.

There is plenty of variability in rice genetic resources. Shrestha et al. [24] evaluated 40 genotypes in Nepal and observed variations in plant height, panicle length, tillers per plant, and grain yield. Following the grouping in clusters, several parentals were identified for breeding programmes.

In Asia, growing more rice with less water is a challenge, and the problem of lower water availability for rice cultivation is a reality. Growing rice under aerobic conditions with supplementary irrigation if rainfall is insufficient—as opposed to continuous flooding—is being tested in India [25]. Suitable genotypes must be selected for this purpose. Grain yield under these conditions was positively correlated with the number of tillers m^{-2} and panicles m^{-2}, but negatively correlated with days to 50% flowering or maturity.

In China, increasing the area cultivated with less water is a goal. Changing from sowing to transplanting led to an overall increase in grain yields in the Han River basin [26] and reduced the amount of irrigation water in regions with a favourable rainfall pattern. In Sevilla (Spain) during the last two seasons, a paddy has not been sown due to a lack of water. In D.O. Calasparra (Spain), there is concern regarding the amount of water strictly needed for rice cultivation considering sustainability; the irrigation system in this area is based on a continuous flow of water from the rivers, which is then re-circulated in the fields.

5. Conclusions

Altogether, it seems feasible to shorten the crop cycle through changing the establishment method from sowing to transplanting, potentially simultaneously reducing the incidence of *P. oryzae* in paddies grown in D.O. Calasparra.

Based on our findings, mechanized transplanting is recommended for farmers in the D.O. Calasparra region to improve yield stability and reduce disease incidence.

Mechanized transplanting offers a viable alternative to traditional methods, providing economic and agronomic benefits.

Further experimentation is required to provide proper agronomic guidelines to farmers with the aim of obtaining profitable grain yields and ensuring the maintenance of rice cultivation in the area.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriengineering6040231/s1, Table S1: Number of *Alternaria sp.* conidia captured with Petri dishes in the rice fields during 2022 [1]; Table S2: Presence of *Pyricularia oryzae*[1] in the rice fields in 2022; Table S3: Presence of *Pyricularia oryzae* [1] in the rice fields in 2023; Table S4: Rice quality: nutritional and mineral composition according to the establishment method in different locations in 2022 [1]; Table S5: Pearson's correlation coefficients (upper matrix) and corresponding *p*-values for H0; Pearson's correlation coefficient = 0 (lower matrix). Significant correlations are highlighted in yellow (p-value $\leq$ 0.05). Data are from 2022; Table S6: Principal component analysis. Data are from 2022; Figure S1: Triangular correlation matrix. Circles represent the magnitude of Pearson's correlation coefficient (size and color), while asterisks indicate statistically significant correlations (p-value $\leq$ 0.05). Data are from 2022.

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