Chapter 1

New Genotypes of Long and Thin Grain Rice and Technology for Production in Mexico: Michoacán State as an Example

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Abstract

In Mexico, the national demand for rice exceeds four times the consumption of the grain produced internally, which has caused growing volumes of imported rice. Long and thin-type rice is the one with the highest consumption. Faced with this problem, a strategy was implemented based on the evaluation, validation, and release of rice materials. Since Michoacán State is involved in rice production, evaluations have allowed the selection of materials, which has resulted in the current availability of a number of advanced experimental lines. Also, the technology that has traditionally been used in the cultivation had changed, so that continuous improvement programs have been developed represented by the system of cultivation in direct sowing in furrows and continuous irrigation. The new varieties do not require continuous flooding, which allows for a greater efficiency in the use of water and soil resources. Studies on rice nutrition in Mexico are still scarce, especially under irrigated conditions. The current has focused on the nitrogen fertilization of this crop since the exploration of the efficient management of soil nutrition is a vitally important issue. Other aspects integrated to the rice technology are the use of a low seed rate and weed management using a new generation of herbicides.

Keywords: elite lines, entire rice, genetic materials, *Oryza sativa*, rice genotypes, rice technologies, "Valley of Apatzingan"

1. Introduction

Of small grain cereals, rice (*Oryza sativa* L.) is a crop of extreme importance in the world. In Mexico, this cereal occupies the fourth place among the most cultivated grains for food purposes, only below corn, beans, and wheat. According to the Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (SAGARPA, by its acronyms in Spanish), it is annually consumed on average 1.3 million tons. This shows that the national demand for rice exceeds four times the production in the country which has caused increasing volumes of rice import. It is important to mention that the long and thin type of rice is the most consumed in Mexico due to its better industrial quality and physical appearance of the grain than other rice types. Due to this, the country has been mainly dependent on imports, adding up to 800,000 tons of grain per year to satisfy the internal market. This situation has brought about dismantling of the "chain" rice, an activity that discourages domestic production; additionally, the said imports tend to grow up to 85% of national consumption [1].

In this situation, the Mexican Rice Council A.C. delivered materials from the Latin American Irrigation Rice Fund (FLAR) to the National Institute of Forestry, Agriculture and Livestock Research (INIFAP, by its acronyms in Spanish), which were the support for undertaking studies oriented toward evaluation, validation, and release of improved rice varieties in Mexico. Both the experimental trials and the validation trials were conducted in the rice-producing areas of the country under experimental designs and applying the methodology of stability parameters, evaluating their response to the different environments and conditions of development [2–4]. The process consisted of the selection of genotypes with desired agronomic characteristics, derived from the crossing of materials in the field. For the last 10 years, INIFAP has been doing an arduous and constant work, so, to date, there are stable varieties of long grain and thin rice. Despite the efforts, not enough long grain rice varieties adapted to the different agroecological conditions are available in the country [5]. However, in some regions, advanced experimental lines have been selected, including the release of the following two varieties with long and thin grain properties: FL05392-3P-12-2P-2P-M registered as INIFLAR R [6] and FL04621-2P-1-3P-3P-M registered as INIFLAR RT [7], which is becoming an alternative to the Milagro Filipino variety that has been intensively and extensively cultivated, despite the remarkable loss of its purity [8]. These outstanding genetic materials are superior to the conventional variety in grain yield, industrial quality, in addition to the characteristics of the long and thin grain type.

It is worth mentioning that one of the aspects that have defined the preference of the consumer is the culinary quality of the rice, also by the industrialists, the industrial quality of the grain is a parameter to be taken into account. Being the state of Michoacán that participates in the production of rice, the evaluations of these lines have allowed to select materials, which has currently resulted in y having a number of advanced experimental lines. Also, the technology that is traditionally used in cultivation has had substantial changes. Therefore, continuous improvement programs have been developed, represented by the direct sowing system in "grooves" and irrigations supplementary, taking into account that as in all crops, water is basic for the rice plant to complete its functions unlike other species; also, water is an essential means for rice to develop and reduce competition of weeds and other plants antagonistic to rice; however, currently, the shortage of water is the main problem for humanity, but the new varieties do not require continuous flooding, which allows to have a greater efficiency in the use of water and a better use of the resources. On the other hand, studies on nutrition in rice cultivation are still scarce, especially under irrigation conditions. These have focused on nitrogen fertilization. Therefore, the exploration of the efficient management of nutrition is a subject of vital importance. Other aspects integrated to the technological "package" of rice are the use of less quantity of seed per area and the management of weeds through new-generation herbicides.

Under these circumstances, it is necessary to promote the production of thin and long grain rice to reduce dependence on the import in order to maintain the balance of the industry in Mexico. As already noted, the strategy for reversing this situation has been the release of high-yield potential rice varieties with the high milling and culinary qualities which satisfies the demand of the industry and consumers.

2. Importance of rice cultivation

Rice is sown in the agroclimatic regions of the humid, sub-humid, and dry tropics of the country, which are differentiated by their temperature, precipitation, and by the sources of

States	Cultivated area (ha)	Grain yield (t·ha^{-1})	Total production (t)	Average price (USD t^{-1})	Total value (USD)
Campeche	9963.5	4.9	49,479.9	209.2	10,354,885.6
Chiapas	537.0	1.8	1004.8	272.2	273,597.4
Colima	3330.0	5.1	17,252.8	236.6	4,082,699.9
Guerrero	390.8	6.2	2443.8	324.4	792,992.4
Jalisco	2998.4	5.3	15,907.2	246.3	3,917,913.5
Mexico	68.0	5.4	372.6	329.6	122,837.7
Michoacán	**3384.0**	**8.7**	**29,454.2**	**240.4**	**7,082,376.0**
Morelos	1323.4	10.1	13,392.8	289.6	3,879,593.4
Nayarit	10,769.5	6.4	69,279.9	239.8	16,614,546.8
Oaxaca	18.0	2.8	50.4	262.5	13,230.0
Tabasco	1621.5	7.1	11,548.8	207.2	2,393,171.2
Tamaulipas	2738.5	6.1	16,886.1	250.0	4,221,530.0
Veracruz	4269.0	6.3	26,969.4	268.4	7,238,917.9
Total	41,411.8	-	254,043.2	-	60,988,324.2

Table 1. The area of cultivation, production, and value of rice in 2016 in selected states of Mexico [9].

Year	Michoacán State			Mexico
	Area cultivated (ha)	Total production (t)	Grain yield ($t \cdot ha^{-1}$)	Area cultivated (ha)
2016	3384.0	29,454.2	8.7	41,411.8
2015	3942.0	33,260.5	8.4	40,637.5
2014	4498.5	39,500.6	8.7	40,642.3
2013	2510.9	22,933.9	9.1	33,137.4
2012	3894.0	35,528.2	9.1	31,795.2
2011	2792.5	25,465.1	9.1	34,037.4
2010	3470.0	31,530.3	9.0	41,747.7
2009	5658.0	48,571.2	8.5	54,230.4
2008	4108.5	29,953.3	7.2	50,285.6
2007	3165.5	29,190.0	9.2	70,948.7
2006	4641.7	42,183.1	9.0	70,469.6
2005	5424.7	49,529.0	9.1	57,479.2
2004	4148.5	35,507.6	8.5	62,389.8
2003	4598.0	37,505.0	8.1	60,043.6
2002	2981.8	23,699.2	7.9	50,457.2
2001	3858.0	29,634.9	7.6	53,231.7
2000	4999.0	34,384.0	6.8	84,068.9

Table 2. The trend in rice area of cultivation, production, and grain yield in the state of Michoacán, Mexico from 2000 to 2016 [9].

water supply to satisfy the water needs of the crop; although they are contrasting, the rice plant adapts to different soil, water, and climate conditions.

In 2016, the total harvested area of rice in Mexico exceeded 41,000 hectares, where 13 states participate in national production (**Table 1**); particularly the state of Michoacán is positioned in the fourth place with 3384 hectares, it is preceded by the states of Nayarit with 10,769 hectares, Campeche with 9963 hectares, and Veracruz with 4269 hectares [9]; however, in terms grain yield, Michoacán has the second place with 8.7 tons per hectare, only preceded by the state of Morelos with 10.1 tons per hectare. In the same year, the total value of the national rice production was USD 60, 988,324.2 (**Table 1**).

In a historical record, during the period from the year 2000 to the year 2016, in the state of Michoacán, the area under rice cultivation has been moderately stable since on average they have been 4000 hectares. However, during the same period, the trend in the area under rice cultivation at the national level showed different picture where it witnessed a substantial decrease from 84,000 ha in the year 2000 to only 41,000 ha in the year 2016 (**Table 2**). Although this 50% reduction in the area under rice cultivation was observed in just 16 years at the national level, the reduction for the state of Michoacán was only 32% (from 4999 to 3384 ha).

Municipality	Area cultivated (ha)	Grain yield (ton·ha^{-1})	Total production (ton)	Average price (USD t^{-1})	Value USD
Apatzingán	26.0	8.5	222.3	237.5	52,796.2
Gabriel Zamora	2068.0	8.7	18,052.6	241.1	4,352,831.6
Múgica	7.0	8.6	60.2	240.6	14,502.4
Nuevo Urecho	48.0	8.6	415.2	240.6	99,907.5
Parácuaro	366.0	8.7	3207.0	239.7	768,933.1
Tepalcatepec	869.0	8.6	7496.9	239.2	1,793,403.7
Total	3384.0	-	29,454.2	-	7,082,376.0

Table 3. The area under cultivation, total production, and total value of rice grown in six municipalities in the state of Michoacán, Mexico [9].

Meanwhile, the municipal structure of the state of Michoacán that participates in the production of rice cultivation is shown in **Table 3**, all corresponding to the name "Valley of Apatzingán", it is a hot climate region. Thus, the municipalities of Gabriel Zamora, Tepalcatepec, and Parácuaro, devoted large areas under rice cultivation. These large areas under rice cultivation in these three municipalities also reflected in high production and economic return.

3. Research on long and thin grain rice in Michoacán State, Mexico

In the state of Michoacán, the Tepalcatepec basin, better known as the "Valley of Apatzingán" or the "tierra caliente," is a region full of contrasts, with a biodiversity that gives origin to different production systems which favors the establishment of different crops, citrus fruits currently predominate; however, as has happened in other places exploited under agricultural activity, the region has been affected by the production system of monoculture type and the indiscriminate use of agrochemicals, which has caused resistance of pests and pathogens, hence difficult to control by the conventional systems.

For the selection of new varieties of rice, the synergy between INIFAP and FLAR allowed the consolidation of this end, where the components of the yield included preliminary tests and national experiments in the different rice regions. It should be noted that the studies focused on the type of grain that determines the preference of the consumer and that also meets with milling, culinary, and nutritional qualities [5], as well as the characterization of phenotypic diversity using agro-morphological traits [10]. Consequently, it is important to follow up on advanced materials, in order to increase the supply and availability of seed. Particularly, the rice cultivation in Michoacán is cultivated in two production cycles that are differentiated mainly by their rainfall regimes and water supply sources to meet their water needs, which are very high given the physiology of the plant. The sowing dates are based on those recommended by the SAGARAPA for the spring-summer productive cycles (June 1 to July 31) and autumn-winter (January 1 to February 15) [11]. The autumn-winter cycle is when there are water deficits due to the demand of water resources for other crops like fruit trees and vegetables; however, in the spring-summer cycle, these problems do not occur due to the rainy season. According to the climatic classification of Köppen [12], the study area is located in a climate Bs1 (h′) w (W) corresponding to the group of semi-dry warm climates (the wettest of the semi-dry warm climates), with rains in summer; the annual average, minimum, and maximum temperatures are of 28, 20 and 37.7°C, respectively; the annual average, minimum, and maximum precipitation are of 834, 500 and 972.8 mm, respectively. The type of soil is grouped in the vertisols "pelic" (clayey) [13, 14]. As for the vegetation, it is represented by the primary types of low deciduous forest, secondary stages of natural succession (different degrees of regeneration after elimination) and bearing shrubby from 4 to 8 m, and arboreal from 8 to 12 m in height [15, 16].

Michoacán State contributes with 11.6% of the national rice production; the advances in the evaluations of these lines have allowed to select promissory materials in substitution of the conventional variety. Based on the above information, the overall objective of this work was to evaluate advanced lines of long and thin grain rice compared with the conventional material under different production cycles and environmental conditions in Michoacán State in Mexico. Therefore, through the selection of promising materials obtained from these trials and through the establishment of validation trials under irrigation conditions, different materials of long and thin grain rice were evaluated and compared with conventional material for the two productive cycles [11].

3.1. Methodology used in the different evaluations of rice genotypes

The different evaluations were formed for the genotypes shown in **Table 4**, where experiments 1 and 2 (E1, E2) were made up of 13 and 14 genotypes [17, 18], respectively, and the validation trials 1, 2, and 3 (V1, V2, V3) were formed by 3, 7, and 3 genotypes [19–21], respectively.

In general, the soil preparation of the experimental trials consisted of basic mechanized work of fallow, plow, and level. In addition, small furrows of 0.2 m were marked between one and another, and the sowing of the seed was done at the seed rate of 80 $kg \cdot ha^{-1}$. Other agronomic practices consisted of irrigation every 5 and 8 days depending on the availability of water, control of weeds using selective pre- and post-emergent herbicides [22], fertilization in two stages (at approximately 20 days after the emergence and at the appearance of floral primordium), and application of fungicides. The experimental design used was Randomized Complete Block where the size of each experimental plot was 200 m^2, and the experimental unit for productivity was formed by four blocks of one linear meter each one and 20 plants for the phenological aspects.

Different sets of data were recorded for the experiments and validation trials. For experiment 1, the number of spikes per panicle, 1000 whole grain weight, 1000 polished grain weight grain yield, and days to harvest were recorded, while for experiment 2, plant height, spike length, number of grains per spike, grain yield, and 1000 polished grain weight were quantified. On the other hand, parameters measured for the validation trial 1 were plant height, 1000 whole grain weight, number of spikes per panicle, spike length, and grain yield while for validation

Tested rice lines	Common name	Genotype	Origin
E1	FL04582	FL04582-5P-6-2P-3P-M	VF (nursery FLAR)-2005 (year of release)
E1, E2, V1,V2	FL04621 (INIFLAR RT)	FL04621-2P-1-3P-3P-M	VF-2005
E1	FL04674	FL04674-3P-8-3P-2P-M	VF-2005
E1	FL04676	FL04676-3P-4-1P-2P-M	VF-2005
E1	FL04835	FL04835-19P-9-3P-1P-M	VF-2005
E1, V2	FL04867 (Marfil)	FL04867-2P-7-3P-3P-M	VF-2005
V2, V3	FL04952 (Lombardia)	FL04952-1P-5-1P-1P-M	Santa Rosa, Colombia
E1, E2, V1	FL05392 (INIFLAR R)	FL05392-3P-12-2P-2P-M	VF-2006
E1	FL05509	FL05509-15P-1-2-3P-M	VF-2006
E1	FL05598	FL05598-5P-3-1P-1P-M	VF-2006
E1, V1	FL05601	FL05601-6P-2-2P-2P-M	VF-2007
E1	FL05655	FL05655-3P-4-2P-2P-M	VF-2006
E2	FL06564	FL06564-3P-1-4P-M	Santa Rosa, Colombia
E2	FL06580	FL06580-3P-6-2P-M	Santa Rosa, Colombia
E2	FL06609	FL06609-11P-12-4P-M	Santa Rosa, Colombia
E2	FL06624	FL06624-4P-4-2P-M	Santa Rosa, Colombia
E2	FL06625	FL06625-3P-5-1P-M	Santa Rosa, Colombia
E2	FL06646	FL06646-10P-7-2P-M	Santa Rosa, Colombia
E2	FL06679	FL06679-3P-5-3P-M	Santa Rosa, Colombia
E2	FL06689	FL06689-1P-2-1P-M	VF-2007
V2	FL06747	FL06747-4P-10-5P-3P-M	Santa Rosa, Colombia
E2	FL07162	FL07162-7P-3-3P-3P-M	VF-2008
E2	FL07562	FL07562-7P-3-3P-2P-M	VF-2008
E2, V2, V3	FL08224	FL08224-3P-2-1P-3P-M	VF-2009
E1	Tomatlán A-97	IR10781-75-3-2-2-0PZ-COMP1	Triple crosses: Sinaloa A80/ITA 231//IR8
E2	Aztecas	C109Cu83-5MCu-11Cu-5Cu-1Cu-1Cu	Triple crosses: Sinaloa A80/ITA 231//IR8
E1, V1, V2, V3	Milagro Filipino	IR8-288-3	IRRI of Filipinas

Table 4. Rice lines investigated in Michoacán, Mexico, indicating their origin and genotypes.

trial 2 were plant height, length of the spike, number of spikes per panicle, number of tillers, 1000 whole grain weight, and grain yield. In addition, the occurrence of phenological events was recorded at the time of more than 50% of the plants. For validation trial 3, only plant height and grain yield were recorded. The data were analyzed using the statistical software SAS Institute package [23], through analysis of variance and comparison of means by Tukey test.

3.2. Results of the different evaluations of rice genotypes

Experiment 1 was developed in the municipality of Gabriel Zamora, Michoacán, Mexico, as shown in **Table 5**, with the exception of 1000 polished grain weight; the other parameters showed significant differences among the materials evaluated. In this case, it is important to highlight the performance of five materials (FL04621, FL04674, FL04674, FL05655, and FL05601) with a grain yield above 9 t·ha^{-1}, surpassing the other materials including Milagro Filipino (**Table 5**).

Regarding experiment 2 developed in the municipality of Parácuaro, Michoacán, Mexico, plant height, spike length, number of grains per spike, and 1000 polished grain weight did not show significant differences while grain yield showed significant differences where materials such as FL06689 and FL05392 gave a grain yield more than 11 t·ha^{-1} (**Table 6**). Also, it should be mentioned that based on results from experiments, promising materials for validation trials were selected.

From the three genotypes selected for the validation trial 1, the analysis of variance showed significant differences only for plant height and the number of spikes per panicle (**Table 7**) where genotype INIFLAR RT had a significantly higher plant height than the other two genotypes. On the other hand, the three genotypes did not have significant differences for 1000 whole grain weight, spike length, and grain yield (**Table 7**). The grain yield for the three genotypes slightly exceeded the regional average reported between 8000 and 8500 kg·ha^{-1} [9]. It should be noted that the validation trial 1 was carried out in the autumn-winter cycle and that included its sowing since the end of 2014 and developed in the first months of 2015 under

Genotype	Number of spikes per panicle	1000 whole grain weight (g)	Grain yield (t·ha^{-1})	1000 polished grain weight (g)	Days to harvest
FL04835	12.8 ab	24 ab	8 ab	20.44	118.8 de
FL05598	13.8 ab	25 ab	5.1 ab	19.62	132 a
FL04582	11 b	22 ab	7.4 ab	22.01	122.3 bcde
FL05509	14.5 a	19 b	6.9 ab	20	118.8 de
Tomatlán A-97	13.3 ab	25 ab	8.6 a	20.43	120.8 cde
FL04867	12.3 ab	27 a	8.6 a	19.83	130.5 ab
FL05392	12.5 ab	26 a	8 ab	21.24	119.5 de
FL04621	13 ab	26 a	9.1 a	21.76	126 abcd
FL04676	13.8 ab	23 ab	7.4 ab	19.58	119 de
FL04674	13.5 ab	24 ab	9.1 a	19.88	122.5 bcde
FL05655	14.3 a	26 a	9.1 a	23.79	122 bcde
FL05601	12.3 ab	23 ab	9.1 a	19.91	129 abc
Milagro Filipino	13.3 ab	24 ab	3.4 b	20.49	116.7 e

Table 5. Results of experiment 1 of rice genotypes in the municipality of Gabriel Zamora, Michoacán, Mexico, during spring-summer cycle 2010 [18].

Genotype	Plant height (cm)	Spike length (cm)	Number of grains per spike	Grain yield ($t \cdot ha^{-1}$)	1000 polished grain weight (g)
FL07562	60.66	25.16	20.2	7.92 cd	22.45
FL07162	60	24.16	19.7	7.88 cd	20.92
FL08224	68.33	24.5	19.03	9.38 abc	21.73
FL06564	73	23.83	23.03	9.32 abcd	22.92
FL06580	57.66	23.06	24.5	8.73 bcd	22
FL06609	66.66	23.73	23.56	8.17 bcd	20.54
FL06624	70	25.56	19.53	5.28 c	21.41
FL06646	70.66	24.73	21.13	12.16 ab	21.09
FL06679	64.33	25.9	23.4	10.75 abc	19.64
FL06689	66.66	26.9	20.13	9.42 abc	24.09
FL06625	67.33	25.33	19.9	8.54 bcd	20.35
FL05392	73	26.33	26.26	11.22 abc	22.12
FL04621	69.66	25.16	22.03	10.51 abc	28.49
Aztecas	63.33	25.33	21.66	12.98 a	24.94

Table 6. Results of experiment 2 of rice genotypes in the municipality of Paracuaro, Michoacán, Mexico, during spring-summer cycle 2014 [17].

Genotype	Plant height (cm)	1000 whole grain weight (g)	Number of spikes per panicle	Spike length (cm)	Grain yield ($t \cdot ha^{-1}$)
INIFLAR RT	71.10 a	25.99	11.50 b	25.10	8
FL05601	66.8 ab	26.02	17.20 a	23.30	8.8
Milagro Filipino	63.00 b	26.00	14.00 b	26.10	8.5

Table 7. Results of validation trial 1 of three rice genotypes in the municipality of Paracuaro Michoacán, Mexico, in autumn-winter cycle 2014–2015 [24].

the condition of irrigation, so unlike the FL05601 treatment, the material INIFLAR RT and Milagro Filipino showed a similar pattern in the number of spikes per panicle and the length of the spike, even in the yield. It is important to note that genotype INFLAR RT was selected for its performance under both irrigated and rainfed conditions [7], but it thrives best in the spring-summer cycle, since it is when the rainy season coincides. Due to its productive capacity and establishment period, Milagro Filipino presented a normal yield, in addition to its loss of purity and mixing with other varieties, considering a selection [8] in the process of degeneration.

In the validation trial 2, the analysis of variance showed significant differences in all quantified parameters (**Table 8**). Plant height and spike length values for genotypes FL06747 and FL08224 were higher than those of INFLAR R and INIFLAR RT. This trend was similar for spikes per panicle, number of tillers, and 1000 whole grain weight, except for genotypes Milagro Filipino, FL06747, and FL08224 where similar results were obtained. Genotypes with a high grain yield were FL06747, INIFLAR R, and Lombardia, while the other genotypes also recorded a reasonable amount of yield surpassing the conventional variety (**Table 8**). As occurred in validation trial 1, validation trial 2 was also established under the conditions of the municipality of Parácuaro, Michoacán, Mexico, and these results corroborate the performance of long and thin grain rice genotypes in order to produce adequate amount during the spring-summer production cycle, also surpassed Milagro Filipino, observing that the characterization of these materials gives distinguishable elements that allow the propitious election, attributed to phenotypic diversity or traits morphological [10]. In this study, plant height ranged from 69 to 88 cm (**Table 8**), while in earlier study involving advanced rice lines, a height of 104 cm was reported [25], although the excessive increase in height is associated with problems of lodging or falling of the stalk on the ground. One quality of Milagro Filipino variety was its reduced plant height due to which no lodging was observed. Therefore, a desired feature of these materials from long and thin grain represents a rice with semi-dwarf or compact stature. On the other hand, spike length, spikes per panicle, and grain weight as well as number of tillers influenced the grain yield. The number of tillers per plant obtained in the current study was similar to the earlier study which reported an average of 13 tillers per plant from advanced rice lines [25]. Even though the stock trends in the components orientate to certain yield, this may vary; treatments FL06747, INIFLAR R, and Lombardia showed the highest yields (**Table 8**) and not necessarily related to grain weight and other components, so that probably could have other factors that influenced the response of the yield-like pathogens [26], loss of grain or empty grains. Despite this, the yields are acceptable and coincide with other reports [7, 27, 28].

Figure 1 shows the time for different phenological events starting from flowering to harvest maturity. Flowering occurred between 74 and 76 days for most varieties, with the exception of INIFLAR RT and Milagro Filipino which flowered after 80 days. The time for successive growth stages of maturity at "milky," "mass," and "harvest" of these varieties followed similar trend to the flowering where early flowering types were also early maturing and late flowering were late maturing. In the face of increasingly unstable climatic changes, an important characteristic that is valued quantitatively and qualitatively is the precocity of the materials, which has to do with the advancement of harvests, but without losing yield or quality; as could be

Treatments	Plant height (cm)	Spike length (cm)	Number of spikes per panicle	Number of tillers	1000 whole grain weight (g)	Grain yield ($t \cdot ha^{-1}$)
FL06747	88.75 a	30.00 a	21.60 a	13.40 a	32.1 a	11.575 a
FL08224	83.95 a	28.50 ab	19.80 ab	11.00 ab	30.2 ab	9.850 ab
INIFLAR R	72.85 b	27.20 bc	15.20 c	9.20 b	25.0 bc	11.512 a
INIFLAR RT	69.85 b	24.90 cd	17.40 bc	10.80 b	23.7 c	9.050 b
Marfil	71.70 b	24.70 cd	17.00 bc	9.20 b	25.0 bc	9.737 ab
Lombardia	71.80 b	25.00 cd	18.80 ab	10.60 b	24.5 bc	10.200 ab
Milagro Filipino	67.95 b	23.00 d	19.40 ab	11.60 ab	28.5 abc	8.200 b

Table 8. Results of validation trial 2 of seven rice genotypes in the municipality of Paracuaro Michoacán, Mexico, in spring-summer cycle 2015 [20].

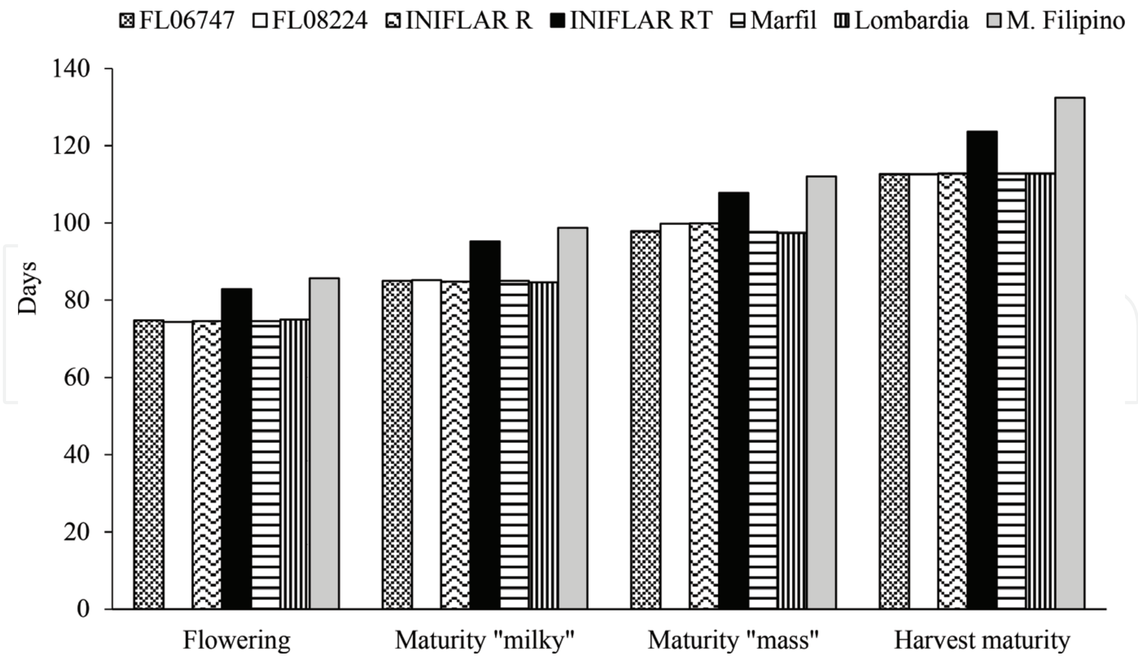

Figure 1. The time of flowering and maturity of seven rice genotypes in validation trial 2 in Paracuaro Michoacán, Mexico, during spring-summer cycle 2015 [21].

observed, the different stages of the maturity of the grain appeared more quickly in the materials of long and thin grain (**Figure 1**), a situation clearly observed in the Milagro Filipino variety. It is also important to point out that in addition to this property, aspects such as tolerance to abiotic stresses need to be explored [29] in order to identify candidate lines with enhanced performance under conditions of low water supply [30] and biotic stresses [26].

On the other hand, **Table 9** shows the results of validation trial 3 experiment where plant height and grain yield were evaluated although significant difference was obtained only for grain yield. It is important to note that this validation trial was developed in the municipality of Nuevo Urecho Michoacán, Mexico, and although the edapho-climatic characteristics suggested in the corresponding section are similar, the grain yield of the FL08224 treatment was inferior to the grain yield presented in the validation plot. With this same material, the interpretation for this purpose may be due to the productive systems from the point of seed quality and adaptability. This situation may occur, since it should be noted that yield is a complex quantitative character that is largely influenced by environmental fluctuations [31].

Genotypes	Plant height (cm)	Grain yield ($t{\cdot}ha^{-1}$)
Lombardia	71.08	12.003 a
FL08224	67.87	7.730 b
Milagro Filipino	68.91	8.255 b

Table 9. Effects of genotypes on plant height and grain yield for validation trial 3 study in rice in the municipality of Nuevo Urecho, Michoacán, Mexico, during spring-summer cycle 2016 [19].

4. Rice production technologies in Michoacán, Mexico

In Mexico, from 1993 to date, the introduction and exchange of rice germplasm is only carried out by INIFAP through the National Bank of Rice Germplasm with headquarters in "Zacatepec" Experimental Field, whose flow comes from international organizations and producer states in the country [32].

On the other hand, the production technology of rice cultivation in the "Valley of Apatzingan", Michoacán, Mexico, represented mainly by the introduction of seed treatment with insecticide and fungicide, the reduction of seed rate per hectare, direct sowing in furrows and irrigation, the use of new-generation herbicides, the optimal application of irrigation quantity, and the use of new varieties, is widely adopted by producers and was obtained through research work carried out by INIFAP [33].

4.1. Direct sowing of seed in furrows

Direct sowing in furrows is considered as an alternative to reduce production costs, make water use and management more efficient since it does not require permanent flooding of the crop; the employed labor also decreases, and it does not require the construction of seedbeds, as well as of rice boards, all without affecting grain yield; this method can be implemented in most land of the region independently of whether you have irrigation or a temporary land with the possibility of irrigation supply [34].

The selection of the best sowing date is a very important decision, but it is not always possible to establish the most suitable date, even under irrigation conditions, sometimes it is not possible to establish the best dates due to the shortage of water or to the priority that the irrigation districts consider the different crops in the region [35]. In general, the sowing dates for the municipalities of the "Valle of Apatzingan" range from January 1 to February 15 (autumn-winter cycle) and from June 1 to July 15 (spring-summer cycle).

As indicated above, direct seeding in furrows has been optimized based on the following settings:

1. A fallow is previously made
2. Cross harrow passage
3. Marking of the furrows with a distance of 20–30 cm between one and the other
4. Sowing the seed manually or with a planter precision
5. First establishment irrigation
6. Weed control with herbicides pre-emergent and in its case post-emergent.

In previous evaluations developed by INIFAP, it has been found that with the furrow seeding system, 80–100 kg of seed per hectare can be used. Higher densities may aggravate problems of lodging during crop maturity due to the weakening of the stems and to the development of a greater height of the plants by an excessive competition [35].

4.2. Seed treatment

Currently, seed treatment is a very important option to reduce the damage caused by fungal diseases and to prevent the attack of soil pests on germination, which is when the rice cultivation is more susceptible. One of the advantages of seed treatment is that it is economical and easy to perform, also to provide the plant with protection that goes from 30 to 40 days after emergence. There are different methods of seed treatment. In rice, the simplest and most used in the region is to start with a previous cleaning in order to eliminate damaged seeds, crop straw, and lumps and stones. Next, the amount of seed to be used for the sowing is spread on a smooth plot of land in order to sprinkle the seed directly with a sprinkler backpack, attaining to moisten it with different existing products: Clotianidin (3 $ml{\cdot}L^{-1}$ of water), Thiophanate methyl (2 $g{\cdot}L^{-1}$ of water), Benomilo (2 $g{\cdot}L^{-1}$ of water), Captan (2 $g{\cdot}L^{-1}$ water), and Imidacloprid (4 $ml{\cdot}L^{-1}$ water). It is generally possible to sprinkle 100 kg of seed using 2–3 L of water plus the product to be used in dye to distinguish that this seed is treated and thus avoid accidents by ingestion [36].

4.3. Efficiency in irrigation water management

In the "Valley of Apatzingan," the most important factors limiting rice production are weeds, and the factors that limit the increase of the sown area are the production costs and the high irrigation volumes that are applied to the crop. A common practice is flood. Nonetheless, within basic crops, rice is the best option that guarantees economic benefits to the regional producer; however, the use of large volumes of irrigation promotes low levels of efficiency of this resource, which limits the planting of a larger area. Therefore, the research work has focused on reducing the volume of irrigation to the crop without reducing yield, in addition to determining the volume of water needed and the frequency of irrigation to obtain a high grain yield. Five treatments were established in the municipality of Parácuaro, Michoacán, Mexico, during three cultivation cycles: (1) control, (2) irrigation every 2 days, (3) irrigation every 3 days, (4) 9 irrigation and 3 periods of flooding, and (5) 12 irrigation and 3 periods of flooding. It is verified that all the treatments significantly reduced the volume of water in comparison with the regional control without affecting the grain yield in a significant way (**Table 10**), which produces a greater efficiency in the use of water. The control produced the

Treatments	Yield ($t{\cdot}ha^{-1}$)	Water amount ($m^3{\cdot}ha^{-1}$)	Quantity of water (m)	Efficiency of water use ($kg{\cdot}m^3$)	Flood time (days)
1 (Control)	9.7	308,500	30.8	3.1	90
2 (irrigation every 2 days)	8.5	17,400	1.7	48.8	4
3 (watering every 3 days)	8.4	11,300	1.1	74.3	4
4 (nine supplemental irrigation and three periods of flooding)	9.2	79,300	7.9	11.6	20
5 (12 supplemental irrigation and three periods of flooding)	9.0	81,900	8.2	10.9	20

Table 10. Grain yield and irrigation parameters in rice, in the municipality of Paracuaro Michoacán, Mexico [34, 37].

largest amount of rice (9.8 t·ha^{-1}), although it was not significantly different from the lowest yield reported earlier [34, 37].

However, the differences in the application of water are highly contrasting (**Table 10**), since the control, due to most of the flooded cycle, required a large amount of water. It is assumed that a large part of the water is lost by draining and it is not possible for the crop to take advantage of all the water supplied. Even when treatments 2 and 3 presented high-yield and low-water volumes applied, they have the limitation of their practical acceptance by the producer because they would raise production costs, for the payment of wages to effect irrigation according to the treatment.

Based on the above, without affecting yield, the time that rice cultivation remains flooded can be reduced by more than 75%, which allows a considerable saving of water. Grain yield is not affected by reducing the volume of water by 20 times, compared to the flooded control. In a practical way, irrigation can be done every 10 days from sowing, with three periods of flooding at 25, 80, and 95 days, of 4, 8, and 8 days, respectively [34].

4.4. Management of nutrition in rice

Rice can be grown in any type of soil, when the humidity conditions are between saturation and field capacity depending on the phenological stage of the crop. The most important characteristics that a rice soil must meet are its ability to absorb and retain moisture; besides their physical and chemical characteristics, hard ground, soil depth, and topography must be taken into account; however, soils with a high clay content are the most appropriate for cultivation, due to their moisture retention capacity. Commonly, agricultural soils contain insufficient amounts of one or more elements essential for nutrition, so it is necessary to add them directly in the form of organic fertilizers or chemical fertilizers; however, a fertile soil contributes nitrogen to the crop, and although it is necessary to make applications of this nutrient, it is not recommended that it be done excessively because it can result in nutritional imbalances, succulence of the plant that favors the attack of pests and diseases and increases the contamination of the aquifers.

The amount of chemical fertilizer that is required to obtain high yields in rice cultivation is variable and is a function of the climate, the soil, and the type of crop that has been established in the previous cycle [38]. Other aspects that influence the efficiency of the fertilizer are the rice genotype and the production system. In addition, the efficient management of fertilization during the first stages of cultivation is influenced by adequate weed control, especially during the first 40 days after sowing, due to the competition effect. Other determining factors are seed quality, plant density, and solar radiation [39].

The effect of fertilizer application on rice in the "Valley of Apatzingan", Michoacán, Mexico, is very clear and perfectly distinguishable between fertilized rice and an unfertilized rice. Rice soils, although fertile, however, are mostly deficient in nitrogen and organic matter, because they have been cultivated for many years through intensive agriculture. However, by applying fertilizers even at low doses (80 units of nitrogen), they can double or triple the grain yield, increasing from 3.0 to more than 7.0 t·ha^{-1}.

Yields vary depending on the variety and type of soil. Through different evaluations of fertilizers developed by INIFAP, doses and recommended methods of fertilization in rice cultivation have been determined. A study developed [36] recommends fertilizing with the dose 180-80 of N-P, applying all the phosphorus (100%) and 50% of the nitrogen, 25 days after sowing and the rest of the nitrogen at flowering. Also, for long and thin grain materials, they respond positively to the dose 240-80 of N-P, respectively. All fertilizer application must be fractioned. During sowing, it is not advisable to supply the nitrogen, while the applications of phosphorus should be 100% of the fertilizer in the sowing. Applications of nitrogen should begin 15 days after seedling emergence with one-third of the total recommended fertilizer dose equal to 80 kg of nitrogen; at the beginning of the "tillering," the other 33% of the dose should be applied, and in the stage of appearance of the floral primordium the rest of the nitrogen. If for practical purposes, it is decided to make two applications of fertilizer, apply 50% of the recommended dose 1 or 2 weeks after the emergency and the rest in the "tillering" stage.

Based on studies on nutrition in irrigated rice in the "Valley of Apatzingan", Michoacán, Mexico, it is reported that after laboratory and statistical analyses, it was determined that in rice for high grain yields, for the "FLAR 13" lines (lines Lombardia and Marfil), the following reference indices are suggested (**Table 11**) [40].

With the previous reference levels, the following determinations were made for the results obtained in the Marfil and Lombardia rice lines, whose analysis results are presented in **Table 12**.

Once the nutritional levels of the outstanding materials of rice are determined, the Kenworthy methodology was applied [41], to evaluate the nutritional condition of the rice, that is to say, its nutritional diagnosis. **Figure 2** shows the nutritional diagnosis obtained in

Chemical element	Nitrogen (%)	Coefficient of variation (%)
Nitrogen	2.90	12.3
Phosphorus	0.15	14.1
Potassium	1.35	13.7

Table 11. Foliar nutritional reference values (%) of the three most important chemical elements for the long and thin grain rice "FLAR-13" in the "Valley of Apatzingan", Michoacán, Mexico [40].

Rice lines	Nitrogen (%)	Phosphorus (%)	Potassium (%)
Marfil	2.2	0.18	1.76
Lombardia	2.4	0.21	1.85

Table 12. Foliar analysis of outstanding rice lines in the "Valley of Apatzingan", Michoacán, Mexico [40].

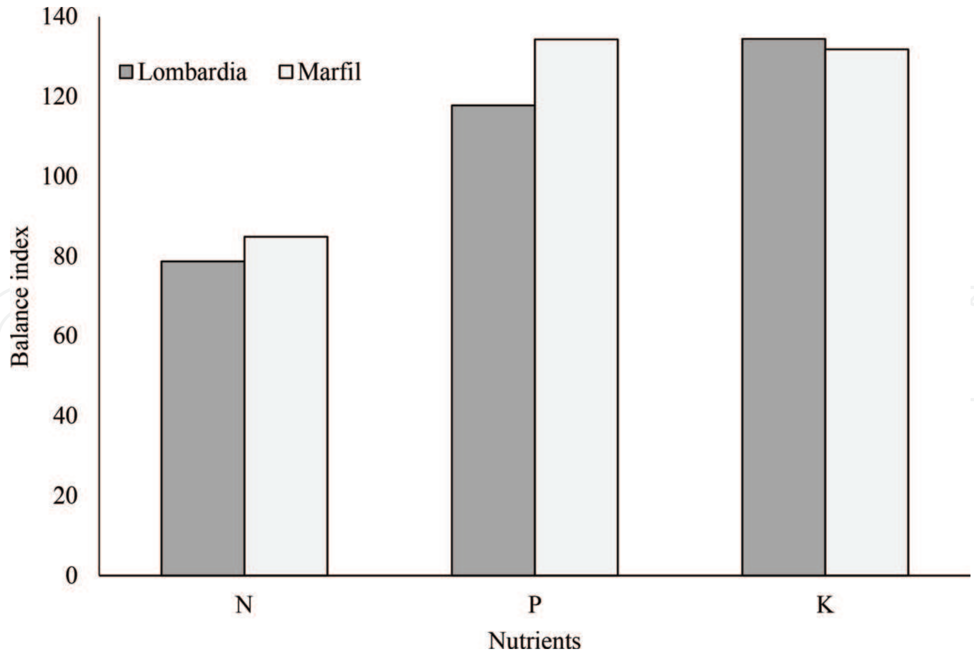

Figure 2. Nutritional diagnosis of two rice lines (Lombardia and Mafil) in the "Valley of Apatzingan", Michoacán, Mexico [40].

two rice materials for the "Valley of Apatzingan", Michoacán, Mexico. As can be seen, there was a higher nutritional imbalance in Marfil line than in Lombardia, while in both rice lines, potassium was the most unbalanced mineral; however, it was notable that the nitrogen was in an adequate balance which may indicate that this element was well supplied and in the proper doses.

Based on this investigation, to produce 1 ton of rice, the plant needs to absorb 20 kg of nitrogen, 4 kg of phosphorus, and 32 kg of potassium. Detailed amounts of nutrients required for rice in the "Valley of Apatzingan", Michoacán, Mexico, based on extraction levels of macronutrients are shown in **Table 13**, where both high and low extractions are observed for each ton of grain produced [40], which serve as reference for designing fertilization program. It should be noted that research has shown that in Michoacán, there is no response to potassium in cereals.

Rice cultivation, as indicated, has an excellent response to fertilization doses; in the Lombardia rice line, the response of the cereal was evaluated at increasing doses of nitrogen, generating the classic linear response, and if the doses continue to grow, then the yield is reduced as shown in **Figure 3**. The function allows the optimization of the amount of fertilizer to be applied as shown in the following sequence [40].

Extraction level	Total N	P	K
High	13.6	2.5	4.9
Low	8.96	2.6	3.6

Table 13. Extraction of macronutrients N, P, K in the rice crop in $kg \cdot t^{-1}$ of whole rice [40].

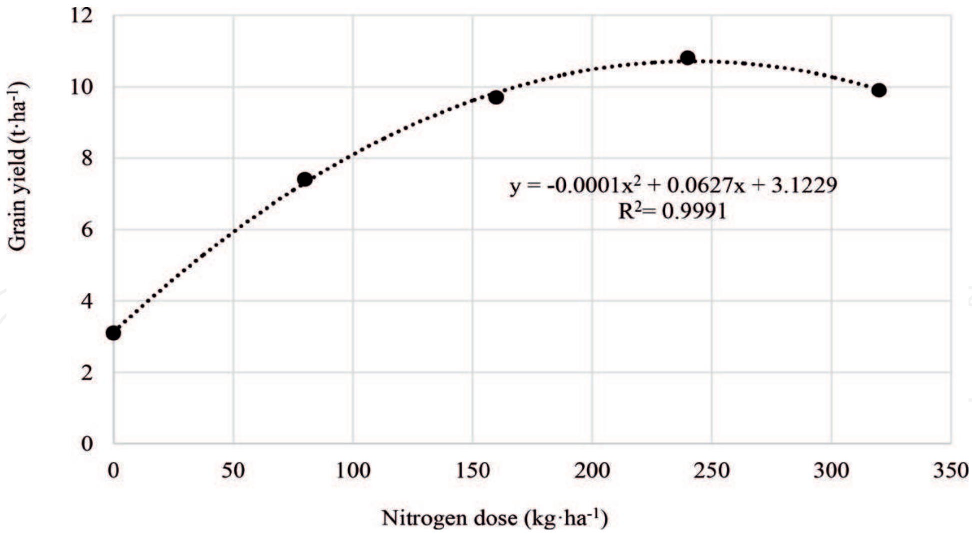

Figure 3. The response of Lombardia rice line to increasing doses of nitrogen [40].

5. Conclusion

Rice cultivation needs to remain under investigation in order to meet the demands of the producers and reduce the excess in imports of the long thin grain of rice, the release materials of long grain and thin rice, for the "Valley of Apatzingan" region is extremely important, thus achieving a variety with high yields under the conditions of irrigation, taking into account that the shortage of water is the main problem, that is why evaluation must be made in the application of the amount of irrigation required without reducing the potential yields; the technology released by INIFAP of direct sowing and irrigation in furrows has proven its effectiveness, and its level of adoption is higher than 90% of rice farmers in the region.

The soils of the region have very good aggregation and moisture consistency but low in organic matter and nitrogen. Hence, fertilizers are essential for achieving high grain yields, and the inclusion of organic fertilizers is an option to improve the physical and chemical properties of rice soils. Weeds are major constraints to rice cultivation. The best time to control weeds using herbicides is at 2–3 leaf stage of rice plant. The control of pests and diseases is necessary to take into account the economic damages they cause.

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