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Utilizing Dominant Early Maturity Genes of Sterile Line UP-3s in Hybrid Rice Breeding to Avoid High Temperature Season

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Abstract

A new sterile line UP-3s, which carries the Dominant Early Maturity Gene (DEMG), was bred on the farm of University of Arkansas at Pine Bluff (UAPB). UP-3s and two check sterile lines, Jin23-A and Xie-A which do not carry the Dominant Early Maturity Gene, were crossed with a group of different maturity restorer lines, PB-1R, PB-5R, PB11, PB-13R, PB-20, PB-21, PB-22R, and PB-23R. Eighteen new hybrid rice combinations of these crosses were then tested at UAPB in 2012 and 2013. The results showed that panicle differentiation (PD) of hybrids from female parent UP-3s (DEMG) crossed with the 8 male parents, were earlier than the hybrids from female parent Jin23-A or Xie-A crossed with the 8 male parents. The PD of these earlier hybrids was before Jun 25 and heading was before July 20. Early PD and heading avoided the high temperature (over 34˚C) period which usually occurs after July 20 in Arkansas. The yields of these earlier maturity hybrids with female parent UP-3s were higher than those of the late maturity hybrids thatwereF1 progeny of sterile lines Jin23-A or Xie-A (these two female parent checks with non-DEMG). These results showed that the DEMG sterile line UP-3s can be adopted in making crosses with later maturity restorer lines to obtain earlier maturity hybrids to avoid the high temperature period in Arkansas.

Keywords

Earlier Maturity, Dominant Gene, Sterile Line, Hybrid Rice, Utilization, Breeding, Avoid, High Temperature

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1. Introduction

The rice heterosis (hybrid vigor) has been known for a long time in rice research and production. Utilization of hybrid rice is an important technology to meet the increasing rice demand in the world. Hybrid rice is more profitable and sustainable for yield in production. Hybrid rice delivers a per capita yield advantage of about 20% over inbred rice with lesser inputs to land, such as water and pesticides [1] (Rice-Tech, 2015). Also hybrid rice provides many other attributes in social and environmental aspects [1] (Rice-Tech, 2015). China is the first country to develop hybrid rice commercially. Hybrid rice research was initiated in 1964 [2] (Yuan, 1966). The essential genetic tools for breeding hybrid rice varieties, such as the male sterile line (A line), the maintainer line (B line) and restorer line (R line), were developed in 1973 [3] (Yuan and Virmani, 1988). The first batch of rice hybrid varieties was released commercially in 1976. Hybrid rice accounts for 50 percent of the total rice growing area, and 57 percent of the total rice output were from hybrid in China recent years. The research of hybrid rice in USA began in 1980s, and the first commercial hybrid rice was released in year 2000 by the Rice Tec company in USA [4] (David Bennett, 2010). Hybrid rice has been widely grown in the US, and now account for about 40% of acreage in Arkansas rice production in 2012-2014 [5] [6] (Jarrod T. Hardke, 2014). UAPB initiated its in hybrid rice research in 2008 [7] (Huang, B. 2012). Many breeding materials have be developed, and used in the hybrid rice research activities.

A period of very hot weather usually occurs in the summer in Pine Bluff in Arkansas. There were about 50 days with daily highest temperature over 34˚C from June 25-August 15 in 2012-2013 (**Table 1**). Rice panicle differentiation (PD) is very sensitive to high temperature. Rice heading usually occurs about 25 days after PD. The germplasm of earlier PD and heading may be away through avoidance to reduce heat-induced sterility at temperature above 34˚C. The best PD growing stage seems to be before June 25 and the heading stage will be before July 20 to avoid the high temperature in Pine Bluff, Arkansas. Therefore developing earlier maturity varieties are very important to the rice production in areas with very high summer temperature.

Breeding for early maturity hybrid rice is normally carried out by using the early maturity female sterile line crossed with an early maturity restore line. But this approach takes time and provides less diversified genetic materials. Another way is to use the sterile line with dominate early maturity gene (DEMG) as female crossed with different late maturity restorer line as male which is quicker, more effective and result in diversified genetics background from restorer materials.

A new sterile line UP-3s, which carries the Dominant Early Maturity Gene, was bred in University of Arkansas at Pine Bluff (UAPB). UP-3s came from Gobo (PI369806, a native rice variety of Surinam in South America)/Zhenshan 97//Xiangzaoxian No. 1, F_6 generation. UP-3s is a sterile line (two line system) with DEMG. Its plant height is about 90 cm and heading days 85 days. The maturity date of its progeny hybrids, crossing with different restorer line, is depending on the maturity of female parent sterile line UP-3s. It can get the earlier hybrids by using this sterile line. Some early maturity hybrid rice combinations have been developed by usingUP-3s crossed with male parents of different late maturity restorer lines in UAPB rice research program 2011 and 2012. [7] [8] (Huang *et al*. 2012, 2015).

Xie-A is a sterile line with non-DEMG. Xie-A came from Ignape Catelo (PI 373138, a native rice variety of Senegal in Africa)/Xieqingzao//Xieqingzao, B_6F_1 generation. Its plant height is 85 cm, heading days is 75 days, and maturity dates of its progeny hybrids, crossing with different restorer line, are depending on the maturity of male parent (restorer lines). Late maturity hybrid rice combinations have been developed by using Xie-A crossed with male parents of different late maturity restorer lines in UAPB rice research program 2011.

Jin-23A also is a sterile line with non-DEMG. Jin-23A came from Ignape Catelo (PI 373138, a native rice variety of Senegal in Africa)/Jin-23//Jin-23, B_6F_1 generation. Its plant height is about 80 cm, the heading days is about 60 days, and maturity date of its progeny hybrids, crossing with different restorer line, are depending on the maturity of male parent (restorer lines). Late maturity hybrid rice combinations have been developed by using Jin23-A crossed with male parents of different late maturity restorer lines in UAPB rice research program 2012.

The two kinds of hybrids above were tested and compared for their agronomic traits and yield in UAPB farm in 2012 and 2013 separately under the weather condition described in **Table 1**.

2. Materials and Methods

Ten hybrids were developed from sterile lines UP-3s (DEMG) and Xie-A (Check, non-DEMG) by separately

Table 1. The daily highest temperature at Pine Bluff from 2011-2013.

Date	2011	2012	2013	Average	Date	2011	2012	2013	Average	Date	2011	2012	2013	Average
6_1	31.9	30.5	30.7	31.3	7_1	32.6	37.2	28.4	32.7	8_1	37	37.9	31.4	35.4
6_2	33.1	26.1	26.7	30	7_2	33.6	36.8	28.5	32.9	8_2	37.5	36	31.4	35.2
6_3	33.9	32	24.9	30.3	7_3	34	33.1	29.1	32.1	8_3	39.5	35.2	33	35.9
6_4	35.7	35.4	25.8	32.3	7_4	35.4	37.6	28.9	34	8_4	42.1	36.4	31.8	36.8
6_5	35.9	29.6	26.9	30.8	7_5	35.8	38.1	29.7	34.5	8_5	38	37.7	32.6	36.1
6_6	35.2	31.4	28.2	31.6	7_6	33.6	37.1	31.8	34.2	8_6	38.9	35.6	34.8	36.4
6_7	35.6	30.6	26.4	30.8	7_7	35.8	38.4	30.9	35	8_7	40.3	34.8	35.9	37
6_8	35.3	29.3	27.6	30.7	7_8	32.2	37.7	32.8	34.2	8_8	39.9	35.6	34.9	36.8
6_9	33.9	31.3	28.7	31.3	7_9	34.7	29.1	33.6	32.5	8_9	37.9	36.2	36.7	36.9
6_10	33.9	32.3	29.3	31.8	7_10	35.3	30.7	34.3	32.7	8_10	32.8	36.4	35.1	34.8
6_11	34.3	32.5	33.6	33.5	7_11	38.6	30.5	36.3	35.1	8_11	32.3	33.4	31.3	32.3
6_12	34.7	34.8	35	34.8	7_12	37.8	29.4	34.5	33.9	8_12	27.4	29.9	35.6	31
6_13	31.1	31.9	33.9	32.3	7_13	37.6	28.7	30.9	32.4	8_13	33.8	33.6	34.5	34
6_14	36.3	30.5	34.5	33.8	7_14	35.2	29.1	29.7	31.3	8_14	29	36.2	28.9	31.4
6_15	35.5	33.3	30.8	33.2	7_15	31.3	29.4	30.8	30.5	8_15	30.7	28.2	26.2	28.4
6_16	34.9	33.6	30.6	33	7_16	33.8	30.2	32.2	32.1	8_16	29.5	30.3	25.4	28.4
6_17	29.6	34.2	31.3	31.7	7_17	33.7	31.8	31.5	32.3	8_17	31.3	35.4	24.2	30.3
6_18	35.1	33.5	28.2	32.3	7_18	31.7	33.7	34	33.1	8_18	35.5	31.3	27.2	31.3
6_19	35.2	33.1	29.4	32.6	7_19	32.9	35.2	33.6	33.9	8_19	28.2	27.1	27.2	27.5
6_20	36.1	33	30.9	33.3	7_20	33.6	36.8	32.8	34.4	8_20	34.8	28.8	30.1	31.3
6_21	35	33	32.1	33.4	7_21	36.8	38.7	34.1	36.5	8_21	34.6	29.9	31.4	32
6_22	32.6	34.1	33.1	33.3	7_22	36.6	33.3	33.1	34.3	8_22	30.7	30.5	33	31.4
6_23	32.7	34.9	32.3	33.3	7_23	35.8	32.5	33.7	34	8_23	35.2	32.3	33.2	33.6
6_24	35.8	36	32.7	34.8	7_24	36.6	33.8	32.2	34.2	8_24	36.3	32.2	33.3	33.9
6_25	33.6	38.2	32.9	34.9	7_25	34.1	34.6	30.4	33.1	8_25	29.1	31.8	33.3	31.4
6_26	36.5	40.7	32.6	36.6	7_26	35.4	35.4	29.2	33.3	8_26	33.6	31.5	32.2	32.4
6_27	36.9	37.2	34.1	36.1	7_27	35	35.8	26	32.3	8_27	30.9	32.9	32.2	32
6_28	36.3	37.7	35.9	36.6	7_28	35.4	32.1	28.3	31.9	8_28	32.1	33.6	32.6	32.8
6_29	28.3	40.7	35.6	34.9	7_29	34.1	37.4	30.5	34	8_29	32.8	32	33.4	32.7
6_30	33.3	39.6	32.2	35	7_30	31.8	36	31.5	33.1	8_30	30.9	34.1	34.2	33.1
					7_31	35.2	40.7	31.6	35.8	8_31	33.9	27.6	35	32.2

crossed with 5 restorer lines PB-1R, PB-11R, PB-13R, PB-20R, PB-21R in 2011. These 10 hybrids and their 7 parents were tested for agronomic traits and yield in the farm of UAPB in 2012. Soil texture is silt loam with PH value of 5.3. The test entries were sowed at April 18 in the greenhouse and transplanted to field 20 days after sowing with 10 feet long, 1 foot space row, and 3 replications for each entry. Weeds were controlled with 9.3 L ha-1 of propanil (3', 4'-dichloropropionanilide) mixed with 0.4 $kg \cdot ha^{-1}$ of quinclorac (3, 7-dichloroquinoline-8-carboxylic acid; Facet, BASF) when the rice were about four-leaf stage. The nitrogen fertilizer was applied pre-flood at 134 $kg \cdot N \cdot ha^{-1}$ at about the five-leaf stage. The flood (underground water from a well) was maintained throughout the growing season. Heading dates were recorded when 50% of the plants were headed. Pa-

nicles were harvested 35 days after heading. Plant heights were measured at harvest. Weights of 100 grains and seed set rate were measured after harvest (seed set rate is the seeds percentage in total of spike lets per panicle), milled rice and head rice and yield were also measured.

Another 8 hybrids were developed from sterile lines UP-3s (DEMG) and Jin23-A (Check, non-DEMG) by separately crossed with 4 restorer lines PB-5R, PB-13R, PB-22R, PB-23R in 2012. These 8 hybrids and their 6 parents were tested for agronomic traits and yields in the farm of UAPB in 2013 in a same soil type and management as in 2012. The test entries were sowed in 3 different dates (April 11, 21 and May 1, respectively) in the greenhouse and transplanted to the field 20 days after each sowing date with 5 feet long, 1 foot space row, and 3 replications for each entry. Heading dates were recorded when 50% of the plants were headed. Panicles were harvested 35 days after heading. Plant heights were measured at harvest. Weights of 100 grains and seed set rate were measured after harvest.

Daily temperatures were recorded by Arkansas SCAN (Soil Climate Analysis Network) Site which is about 50 meters away from the field (**Table 1**). Yields had been analyzed by analysis of variance (ANOVA) among entries (lines) with Duncan multiple comparisons, and descriptive of means and standard errors for each entries (SAS program, v 12.0).

3. Results and Discussions

In year 2012, the 4 hybrids (**Table 2**: UP-3s/PB-13R, UP-3s/PB-11R, UP-3s/PB-21R and UP-3s/PB20R), which were developed from sterile line UP-3s by crossed with late maturity restorer lines PB13R, PB11R, PB21R, and PB20R, headed between July 11-14 with 84 - 87 heading days (total days from sowing date to heading date), and their yields were 11,039, 10,985, 10,394, and 10,756 kg/hectare, respectively. The other 4 hybrids: Xie-A/PB-1R, Xie-A/PB-13R, Xie-A/PB-11R, Xie-A/PB-21R and Xie-A/PB-20R which developed from check sterile line Xie-A by crossed with the same restorer lines, headed between July 22-31 with 95 - 104 heading days, and

Table 2. Hybrid rice yield test at UAPB 2012.

Oder	Cross, parent	Heading date month_date	Heading days Sowing-heading	Yields		Plant height (cm)	Weight g/100 grains	Seed set (%)	Milled rice (%)	Head rice (%)
				kg/h	Std Error					
1	Xie-A/PB-1R	7_12	85	10,778a	175.5	115	3.1	89.2	70.5	47.4
2	Xie-A/PB-13R	7_22	95	9448c	83.4	117	3.2	80.6	70.1	49.5
3	Xie-A/PB-11R	7_23	96	8588e	127.9	126	3.1	83.8	72.1	50.3
4	Xie-A/PB-21R	7_26	99	9026d	51.7	122	3.2	82.1	74.4	52.3
5	Xie-A/PB-20R	7_31	104	8512e	100.4	121	3.3	81.9	74.8	54.3
6	UP-3s/PB-1R	7_11	84	10,860a	81.7	116	3.1	92.4	70.8	50.3
7	UP-3s/PB-13R	7_11	84	11,039a	79.5	118	2.9	95.9	73.7	51.2
8	UP-3s/PB-11R	7_12	85	10,985a	67.9	119	2.8	94.9	72.1	52.3
9	UP-3s/PB-21R	7_12	85	10,394b	125.4	119	2.9	97	68.7	56.1
10	UP-3s/PB-20R	7_14	87	10,756a	111.0	113	3.1	97	74.5	51.3
11	Xie-A (check)	7_2	75							
12	UP-3s	7_14	87							
13	PB-1R	7_19	92	6908gh	112.5	116	3.3	80.2	70.3	50.1
14	PB-13R	8_2	106	7093g	61.7	99	3.4	76.9	71.4	46
15	PB-11R	8_6	110	6729i	39.9	93	3.1	75.4	72,2	54
16	PB-21R	8_8	112	7711f	175.7	107	3.2	75.9	69.6	46
17	PB-20R	8_11	114	6832gh	84.9	115	3.3	74.9	68.5	47

Means with the same letters are not significant at $\alpha = 0.05$.

their yields were 9448, 8588, 9026, and 8512 kg/hectare, respectively. The yields of hybrid combinations developed from UP-3s were significantly higher than the yields of combinations developed from Xie-A (**Table 2**). The heading days and yields were similar for the hybrids UP-3s/PB-1R and Xie-A/PB-1R that were developed from sterile lines UP-3s and check Xie-A by crossed with the restorer line PB-1R due to PB-1R having early maturity gene. They headed in July 11-12 with 84 - 85 heading days, and yield 10,860 and 10,778 kg/hectare, respectively (**Table 2**).

The cross of UP-3/PB-13R matured 11 days earlier and yielded 16.8% higher than the cross of Xie-A/PB-13R; The cross of UP-3s/PB11R matured 11 days earlier and yielded 27.9% higher than the cross of Xie-A/ PB-11R; The cross of UP-3s/PB-13R matured 14 days earlier and yielded 15.3% higher than that cross of Xie-A/PB-21R; The cross ofUP-3s/PB-20R matured 14 days earlier and yielded 26.4% higher than the cross of Xie-A/PB-20R. All these results are due to the UP-3s has DEMG, and Xie-A has no DEMG (**Table 2**).

The heading days and yield of the crosses UP-3s/PB1R and Xie-A/PB1R were similar because PB-1R is an earlier season restores line (**Table 2**).

In the year 2013, 4 hybrids (**Table 3**: UP-3s/PB-13R, UP-3s/PB-5R, UP-3s/PB-22R, and UP-3s/PB-23R), which were developed from Up-3s crossed with late maturity restorer lines PB-13R, PB-5R, PB-22R, and PB-23, headed between July 5-7 with 84 - 87 heading days in planting stage I (April 11); headed between July 12-14 with 82 - 84 heading days in planting stage II (April 21); and headed between July 18-20 with 78 - 80 heading days in planting stage III (May 1). The other 4 hybrids: Jin-23A/PB-13R, Jin-23A/PB-5R, Jin-23A/PB-22R, and Jin-23A/PB-23R, which were developed from check sterile line Jin-23A by crossed with the same group of restorer, headed between July 21-29 with 101 - 109 long heading days in the Stage I, between July 28-August 6 with 98 - 104 heading days in the stage II, and between August 4-August 13 with 95 - 104 heading days in the stage III. The 4 hybrids from Jin-23A had longer heading days there for matured later than the 4 hybrids from Up-3s (**Table 3**).

The yields of the crosses, UP-3s/PB-13R, UP-3s/PB-5R, UP-3s/PB-22R, and UP-3s/PB-23R, were 11,649, 17,980, 11,725, and 11,627 kg/h, respectively in planting Stage I, 11,009, 11,152, 10,928, and 11,073 kg/h, respectively in stage II, and 10,882, 10,919, 10,371, and 10,694 kg/h, respectively in stage III. Yields of the crosses, Jin-23A/PB-13R, Jin-23A/PB-5R, Jin-23A/PB-22R, and Jin23-A/PB-23R were only 9422, 9344, 9846, and 9637 kg/h, respectively in planting Stage I, 3979, 8948, 9489, and 9214 kg/h, respectively in stage II, and 8825, 8644, 8490, and 8272 kg/h, respectively in stage III. The average yields of UP-3s combinations were significantly higher than the yields of Jin-23A combinations of the three planting dates. The heading days and yields of cross UP-3/PB-13R were 16, 13, and 17 days earlier and 23.6%, 17.4%, and 23.3% higher than the cross Jin-23A/PB-13R in planting stage I, II, and II, respectively. The heading days and yields of cross UP-3/PB-5R were 17, 17, and 18 days earlier and 28.2%, 24.6%, and 26.3% higher than the cross Jin-23A/PB-5R in stage I, II, and II, respectively. The heading days and yields of cross UP-3/PB-22R were 21, 19, and 22 days earlier and 19.1%, 15.2%, and 22.2% higher than cross Jin-23 A/PB-21R in stage I, II, and III, respectively. The heading days and yields of cross ofUP-3s/PB-23R was 25 days, 24 days, and 25 days earlier and 20.6%, 20.2% and 29.3% higher than the cross Jin-23A/PB-23R in planting stage I, II, and III, respectively. All the results demonstrated that DEMG will make earlier PD and result earlier heading, and gain higher yields than NO-DEMG in this weather condition (**Table 3**).

The results suggest that earlier planting results in higher yields. The yields of hybrid UP-3s/PB-13R in the first stage were 5.8% and 7.1% higher than that in the second and the third stage, respectively; The yields of hybrid UP-3s/PB-5R planted in the first stage were 7.2% and 9.7% higher than that in the second and third stage, respectively; The yields of hybrid UP-3s/PB-22R planted in the first stage were 7.3% and 13.1% higher than that in the second and third stage, respectively; The yields of hybrid UP-3s/PB-23R in the first stage were 5.0% and 8.7% higher than that in the second and third stage, respectively; The same trend also holds for the hybrids from Jin-23A, which does not have DEMG (**Table 3**).

These results showed that the early maturity hybrids with DEMG sterile female parent had higher yields than late maturity hybrids with non-DEMG sterile female parent, and the yield of earlier planting was higher than that late planting stage for the same hybrid. These results indicate that their PD (the panicle differentiation stage) had avoided the high temperature period. To achieve higher yield under the similar weather condition, the PD should be before June 25 and heading stage should be before July 20. The growing stage of a variety from sowing to heading should be earlier than 90 days to achieve higher yield in rice growing areas with high temperatures.

Table 3. Hybrid rice yield test at UAPB, 2013.

Oder	Hybrid or parent	Heading date (month_date)			Heading days			yield (kg/h)					Plant height (cm)			Weight (g/100 gran)			Seed set (%)		
		I	II	III	I	II	III	I	II	III	Average	Std Error	I	II	III	I	II	III	I	II	III
1	UP-3s/PB-13R	7_5	7_13	7_18	85	83	78	11649.5	11008.5	10882.0	11,180a	411.5	107	111	105	3.3	3.4	3.1	93.8	89.7	86.5
2	Jin23A/PB-13R	7_21	7_28	8_4	101	98	95	9422.0	9378.5	8825.3	9209b	332.7	105	102	101	3.2	3.4	3.6	92.8	90.6	79.9
3	UP-3s/PB-5R	7_07	7_14	7_20	87	84	80	11979.7	11152.3	10918.5	11,350a	557.6	99	96	100	3	3.1	3.5	88.9	75.3	71.6
4	Jin-23A/PB-5R	7_24	8_1	8_7	104	102	98	9344.0	8948.3	8644.0	8979b	350.9	113	105	104	2.6	3	3	82.5	89.8	82.4
5	UP-3s/PB-22R	7_6	7_14	7_20	86	84	80	11724.5	10927.7	10371.0	11,008a	680.3	97	98	103	3.1	3.4	3.5	84.2	84.8	87.6
6	Jin-23A/PB-22R	7_27	8_3	8_11	107	104	102	9846.3	9488.7	8489.75	9275b	703.1	113	115	112	3.2	3	3.2	88.5	89.6	88.3
7	UP-3s/PB-23R	7_4	7_12	7_19	84	82	79	11626.5	11073.0	10694.0	11,131a	468.9	97	93	98	3	3.2	3.3	96.4	93.1	70.8
8	Jin-23A/PB-23R	7_29	8_6	8_13	109	107	104	9636.75	9214.0	8272.0	9041b	698.6	109	118	105	2.6	2.3	2.8	67.1	83.6	72.3
9	Jin-23A	6.19	6.26	7.3	68	66	63														
10	UP-3s	7_4	7_12	7_20	84	82	80														
11	PB-13R	7_29	8_7	8_15	109	108	106	7806.0	7335.5	6961.0	7368c	423.4	98	95	97	3.2					
12	PB-5R	8_3	8_11	8_19	114	112	110	7640.5	7313.7	6812.7	7256c	416.9	96	99	97	3.3					
13	PB-22R	8_7	8_13	8_20	118	114	111	7758.0	7191.0	6856.2	7268c	455.8	99	100	102	3.1					
14	PB-23R	8_10	8_17	8_25	121	118	114	7453.2	6812.0	6529.7	6932c	473.1	93	92	95	2.8					

I planted April 11, II planted April 21, and II planted May 1. The means with the same letters are not significant at $\alpha = 0.05$.

These results suggest that the better, quicker and more effective way to get the earlier maturity hybrids with the genetic diversity is to cross the DEMG sterile line with the late maturity restorer lines. The Up-3s is an excellent DEMG sterile line to make new early maturity hybrids with late maturity restorer line. This line and can be directly used in the hybrid rice seed production.

These results also suggest that the UP-3s is an ideal line to be used in new sterile line breeding through making crosses with other maintain lines and for screening new DEMG sterile lines in the breeding program.

These results suggest that the early PD and heading maybe one way to reduce heat-induce sterility at temperature above 34˚C. Late maturity restorer lines are normally used to make the late maturity hybrids with normal sterile lines, but they can also be used to breed early maturity hybrids through crossing with DEMG sterile line such as UP-3s which is quicker, more effective and can result in diversified genetic background from restorer materials. This technology could greatly contribute to hybrid rice breeding and seed production in the future.

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