ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 2022 – December 31, 2022

PROJECT TITLE: Weedy Red Rice Control in Rice

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LEVEL OF 2022 FUNDING: **$49,008**

OBJECTIVES OF PROPOSED RESEARCH:
1. To continue to assess the current distribution of CA weedy red rice
2. To expand our knowledge of weedy red rice ecology under field conditions
3. To test the new biotypes found in 2018-2020 for shattering and dormancy
4. To finalize analysis of field data from years 2018-2021
5. To disseminate pertinent results and best management practices to rice growers and other stakeholders

BACKGROUND AND SUMMARY:
The overall goal of this research project is to continue to provide updated information on the spread, management, and identification of weedy rice in California. A complimentary proposal (since 2018) was funded through the Presidential Endowed Fellowship for rice and covers some of the costs of this project through 2022. To date, this project has produced comprehensive genetics data on weedy rice in California, phenotypic data for identification, distribution of weedy rice biotypes, and has continued to identify possible new biotypes every year. The project has also produced preliminary management data (using a stale seedbed), emergence data under different irrigation conditions, and preliminary data on fall tillage and winter flooding as a

management tool. It has also tested for spot-spray herbicides, which has enabled the submission of data to the EPA and DPR for use of a spot-spray herbicide in California rice, and the discovery of SUPRESS® as our current spot spray herbicide. Our current year's research (2022) focused on identifying and categorizing possible new biotypes, as well as continuing work on use of a fallow (managed and unmanaged) as a control measure.

OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

Objective: To continue to assess the current distribution of CA weedy red rice

1.1 Survey and Grower Interviews.

Since the beginning of the 2016 season, the UCCE Rice Team has been working together with growers, Pest Control Advisers, and County Agricultural Commissioner's offices to identify weedy rice infestations. By the end of the 2016 season, we had identified 5 distinct ecotypes (populations). The infested fields covered over 10,000 acres and were found in every major rice-growing county in California, except Sacramento County. As of the end of 2018, the total acreage was up to 13,866 acres. In 2020, a comprehensive, basin-by-basin survey was conducted over approximately 11,000 acres. Infestation levels were noted (on a 6-level rating scale), and the survey was conducted at the basin level, whereas previously, all surveying had been conducted at the field level. Across the rice-growing region, Sutter county had the highest number of infested acres, whereas Yolo county had the lowest (no fields currently infested) (Table 1). Weedy rice was found on 2237 acres.

When taking into account the approximate total acreage of rice in California, approximately 500,000 acres, weedy rice infestations have been found on only 0.4% of the acreage, a very small area, in comparison to other rice-growing regions of the world.

The acreage by type is important to note (Table 2): Type 1 covers the most acreage, at 1220 acres. Since Type 1 is the most similar (phenotypically) to the medium-grain Calrose varieties (straw-hulled, awnless), it makes sense that growers and PCA's would have difficulty identifying it, allowing it to spread easily. Type 2 is the second most widespread, with 692 acres. The widespread acreage of Type 2 may be related to the fact that it looks quite similar to some of our specialty varieties. Type 3 acreage is still mostly contained to just a few locations, but it has persisted at those locations for more than 10 years in some cases. Both Types 4 and 6 are found at one site each. Type 5 was not found on any acreage at all, most likely due to the use of certified seed. Type 5 has low dormancy, meaning that most of it will come up, allowing it to be rogued. If the seed is planted with certified seed, no new seeds are being introduced into the field.

Table 1. *Surveyed acreage per county in 2020, with number of acres surveyed, number of acres infested, and percentage infested.*

Counties	Surveyed (ac)	Infested (ac)	Infested (%)
Butte	1823	430	23.59
Glenn	1155	388	33.59
Colusa	1226	330	26.92
Yuba	1666	415	24.91
Sutter	3318	642	19.35
Placer	305	32	10.49
San Joaquin	0	N/A[a]	N/A[a]
Sacramento	0	N/A[a]	N/A[a]
Yolo	1288	0	0.00
Total	**10781**	**2237**	**20.75**

[a]Due to difficulties with field access, San Joaquin and Sacramento Counties were not surveyed in 2020, but acreage was updated in 2021 (not included in this report).

Table 2. *Acreage per biotype across the counties surveyed in 2020. Counties included all rice-growing counties except for San Joaquin and Sacramento.*

Biotype	Acres	%
1	1220	54.54
2	692	30.93
3	292	13.05
4	13	0.58
5	0	0.00
6	20	0.89
7	0	0.00
Total	**2,237**	**100%**

In 2017, we had a total of 53 samples submitted for testing, and 15 were confirmed to be weedy rice. The California Crop Improvement Association (CCIA) found eight seed fields infested with weedy rice (all were rejected as seed fields). Three of the fields were new medium-grain seed fields (never before been in the seed certification program); one field was a previously-certified medium-grain seed field; and four fields were specialty variety seed fields newly submitted to the QA program. In 2018, 25 samples were submitted. 5 were confirmed to be weedy rice, in a total of 4 sites (1 site had 2 types). One new biotype was found, Type 6. A preliminary phenotypic assessment describes its characteristics as: black-hulled, awned (awns are red in color), and it is tall (similar in height to types 1, 2, 3, and 5). It was found at only one location, in Butte County. In 2019, nine samples were submitted. Out of the nine samples, only 5 samples were weedy rice, mostly Type 1. One new biotype was identified, Type 7. It was found only at one location, in Butte County. The preliminary phenotypic assessment is: straw-hulled, awned (awns are red in color), no color on the nodes (stem), and a height that is similar to the previously-described types.

In 2020, out of 31 samples submitted, six were confirmed to be weedy rice: three new sites, in Sutter (Type 1), Yuba (Type 1), and San Joaquin (Type 1). Three current locations had additional types, one location in Yuba, and two locations in Butte. Additionally, there were 4-5 samples that were questionable, and need to be further confirmed by shattering and dormancy testing in the lab. One type (found in both Yuba and Sutter) was straw-hulled, with awns, and is white-pericarped and short-grained. Another sample (found in Yuba and Sacramento) was straw-hulled, long-grained, with red pericarp, and no awns. Both potential new types shattered (in the greenhouse), but further testing is necessary to be sure. If the white-pericarped type turns out to be weedy (shattering with dormancy), it would be the first weedy rice type lacking red pericarp in California. A number of seed fields were also found contaminated with weedy rice (primarily Type 5) and were rejected. It is unknown at this time the primary means of weedy rice spread, but shared equipment (including airplanes) is strongly suspected. At the time of this report writing (January 21, 2022), the experiment to confirm biotypes 6 and 7, as well as the questionable types has begun in the UC Davis greenhouse.

In 2021, more than 30 samples were submitted, and 6 were confirmed to be weedy rice: one previously-infested ranch in Yuba County (Type 5), three new ranches infested in Glenn County (2 with Type 5, and 1 with Type 1). We also had two new unknown locations (Type 2 and Type 3), that were submitted by a seed company. We are in the process of investigating to determine the location of each field.

In 2022, we did had 6 samples submitted, none of which were weedy, likely due to the low acreage of rice planted. We encouraged many growers to take out fields that had been previously infested with weedy rice, as a control measure, and that likely contributed to the low submissions as well.

All previously-infested weedy rice fields (found from 2016-2019), were re-surveyed in the 2020 season on a per basin basis and results were reported to the California Rice Commission (maps and acreage reported in previous figures). A larger paper with the survey results is forthcoming. In 2021, we surveyed new fields found in 2020 as well as fields we were unable to access in 2020 and added the acreage to the survey.

Objective: To expand our knowledge of weedy red rice ecology under field conditions

2.1 In-Season Field Trials.

Methods

Due to issues with the field setup, location, and irrigation setup at UC Davis, we did not move into the use of rotational crops of any kind in the field location where the weedy rice was seeded.

Instead, we looked at fallow systems to manage weedy rice. Since many growers are using fallow or managed fallow to control weedy rice, this may yield more applicable and useful data for California growers than crop rotation. The treatments were as follows:

- Treatment 1: Fallow (no irrigation)
- Treatment 2: Managed fallow (1 irrigation flush, followed by spray of a non-selective herbicide)
- Treatment 3: Managed fallow (2 irrigation flushes, each followed by spray of a non-selective herbicide)

The main plots were set up in spring 2018 with levees in between, to maintain differing water levels between the plots. All fields were tilled in the spring of 2018 and each spring following (2019, 2020). Fields were chopped in the fall of 2018, 2019, and 2020. No burning or flooding took place over the winter, due to restrictions on water usage at the UC Davis Agronomy Field Headquarters.

Within each treatment plot (basin), weedy rice biotypes 1, 2, 3, and 5 were seeded in plots (8 feet by 150 feet). Plots were replicated three times per biotype within each basin, in a Complete Randomized Design. A portion of each basin was also left weedy rice-free, to allow for the collection of data on the rice variety without competition from weedy rice. 2018 was an establishment year for the weedy rice populations. In 2019, due to bird damage from 2018, weedy rice was again seeded onto the soil surface in the plots.

In the spring of 2021 and 2022, all three basins were soil sampled to assess weedy rice seedbank levels, before application of water to the soil. Soil samples are currently being washed to assess the number of weedy rice seeds per area of soil (same protocol as in previous years. Each basin was fenced to ensure no geese enter the plots (similar to previous years). In Treatment 1, the field remained fallow and was monitored for weed emergence. In Treatment 2, the field was flushed at the beginning of the season, and monitored for weed emergence. In Treatment 3, the field was flushed at the beginning of the season and was monitored for weed emergence. It was flushed a second time in July (see treatment and flush timings in Table 3).

Approximately a week or two after flushing both Treatment 2 and Treatment 3 were sprayed with glyphosate (Roundup WeatherMAX®). It was applied to one-third (8 ft by 50 ft area) of each weedy rice plot at a rate of 2.33 L ha^{-1} (32 fluid ounces per acre), which is the label recommended rate for weedy red rice control. The applications were made using a CO_2-pressurized (30 PSI) hand-held sprayer equipped with a ten-foot boom and 8003 nozzles, calibrated to apply 20 gallons of liquid per acre.

Counts of weedy rice plants were taken in 10-12 10 cm x 10 cm quadrats per plot, in both the sprayed and non-sprayed parts of each treatment basin, right before each spray application. Visual assessments of percent weedy rice cover were taken at 30 and 60 days after initial irrigation application (including in the fallowed field).

Table 3. *Key dates for irrigation and glyphosate applications in 2021 and 2022.*

Treatment Dates	2021	2022
First Flush	May 27-28	May 27-28
1st Spray	June 18	June 9
Second Flush	July 7	July 8-11
2nd Spray	July 22	July 20

In the spring of 2019, 2020, 2021 and 2022 soil samples (to assess the weedy rice seedbank) were taken from each 8 ft x 150 ft weedy rice plot. Samples were collected from the center of each plot, at 10', 30', 50', 70', 90', 110', and 130' from the north end of each plot, to a depth of approximately 6 inches, for a total of 84 samples per basin. Soil samples were refrigerated until processing. A constant volume of 990-cm^3 of soil was removed from each sample, which was the volume processed. Samples were processed by dissolving them in a saline solution to extract the organic matter. Any undissolved soil was then washed through a strainer to ensure maximum seed extraction. All recovered rice seeds were subjected to a potassium hydroxide test (KOH test) to determine if they were red pericarped (red branned). All seeds testing positive for the KOH test were assumed to be weedy rice, since the soil samples were all collected from fields that were planted with brown pericarped varieties (M-105).

Results

In the fallow treatment, no weeds of rice emerged. Under the managed fallow treatments (2x flush and 1x flush), no weeds of rice emerged except for weedy rice. The field does have a known population of barnyardgrass, but it did not emerge. Weedy rice emerged under the two managed fallow treatments (Table 4). There appears to be a small difference in weedy rice emergence between the two fields (June 18 rating, Table 4), but it is not known if it is significant at this time. In the non-sprayed plots, even without the use of an herbicide, there was some weedy rice mortality (July 22 rating, Table 3). In the sprayed plots, most of the weedy rice was cleaned up in both fields. At a timing near heading (10/6/21-10/15/21, Table 4), no weedy rice plants survived to produce seed. This is a very positive outcome, as it indicates that the use of the managed fallow can effectively reduce weed seeds in the soil, without contributing weed seeds bank into the seedbank for the following season.

Weed cover assessments were made at 30, and 60 days after the first flush of water was made on the field (Figure 1), as well as at about two weeks after each spray. The percent cover was assessed on a per-plot basis (8 ft by 50 ft), for all weed species combined, as weedy rice was too small to identify at the cover assessment scale. The weeds were non-rice weeds, a mix of common lambsquarters, annual morningglory, hairy nightshade, velvetleaf, and field bindweed, among others. None of the weeds are common to rice. The treatment that was most effective at long-term control throughout the first season was Treatment 3 (2 flushes and 2 sprays). Although early weed control seemed good after the first spray, the weeds had grown back and the control looked no different from the untreated control at 60 days after treatment, in Treatment 2 (one spray and flush). In 2022, no weedy rice emerged, and percent weed cover for non-rice weeds was much higher on average than in 2021. In both 2021 and 2022, weed cover was lowest in the treatment with 2 flushes and 2 sprays, in comparison to all other treatments (and it remained lower over the course of the two season).

Table 4. *Emergence of weedy rice about 2 weeks after a flush (June 18, 21) and about 2 weeks after the first spray and a second flush (July 22, 2021), as well as the number of headed weedy rice plants October 6 to October 15, 2021. No weedy rice plants emerged in 2022.*

	6/18/2021			7/22/2021		10/6/21-10/15/2021	
	Plants m^{-2}	SE		Plants m^{-2}	SE	Headed Plants m^{-2}	SE
2x Flush[a]	329.09	87.66	**Sprayed**	0.00	0.00	0.00	0.00
			Non-sprayed	181.25	36.60	0.00	0.00
1x Flush[a]	224.55	28.76	**Sprayed**	9.72	5.97	0.00	0.00
			Non-sprayed	54.17	20.83	0.00	0.00

[a]2x Flush: irrigated 5/27-28, 6/7, 7/7; sprayed 6/18, 7/22

[a]1x Flush: irrigated 5/27-28, 6/7; sprayed 6/18

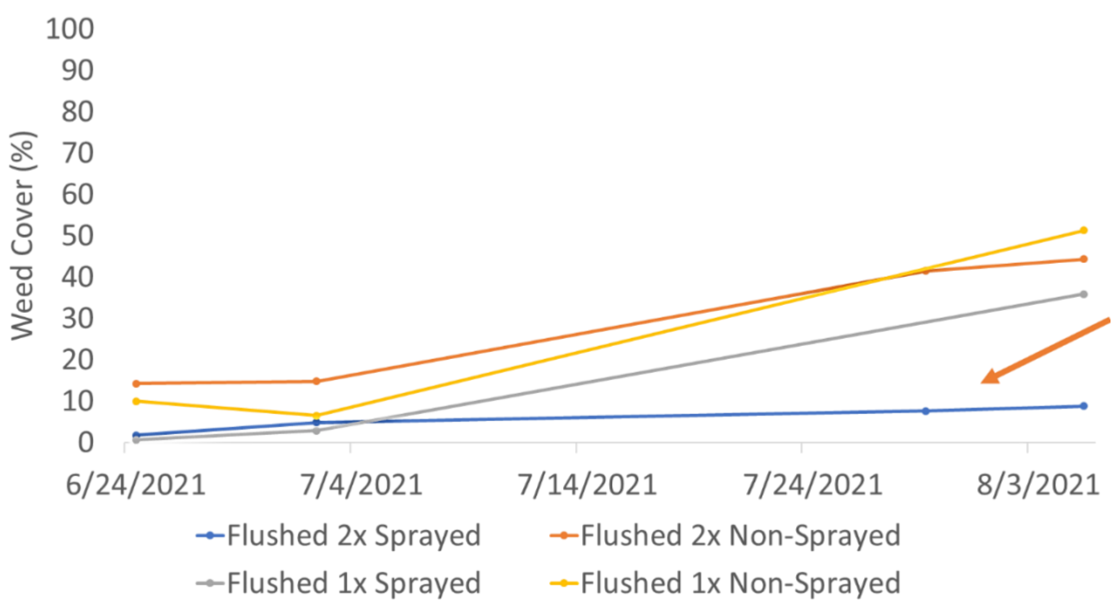

Figure 1. *Percent cover of non-rice weeds in 2021, at approximately 1 month, 2 months, and 3 months after initial water application to the field.*

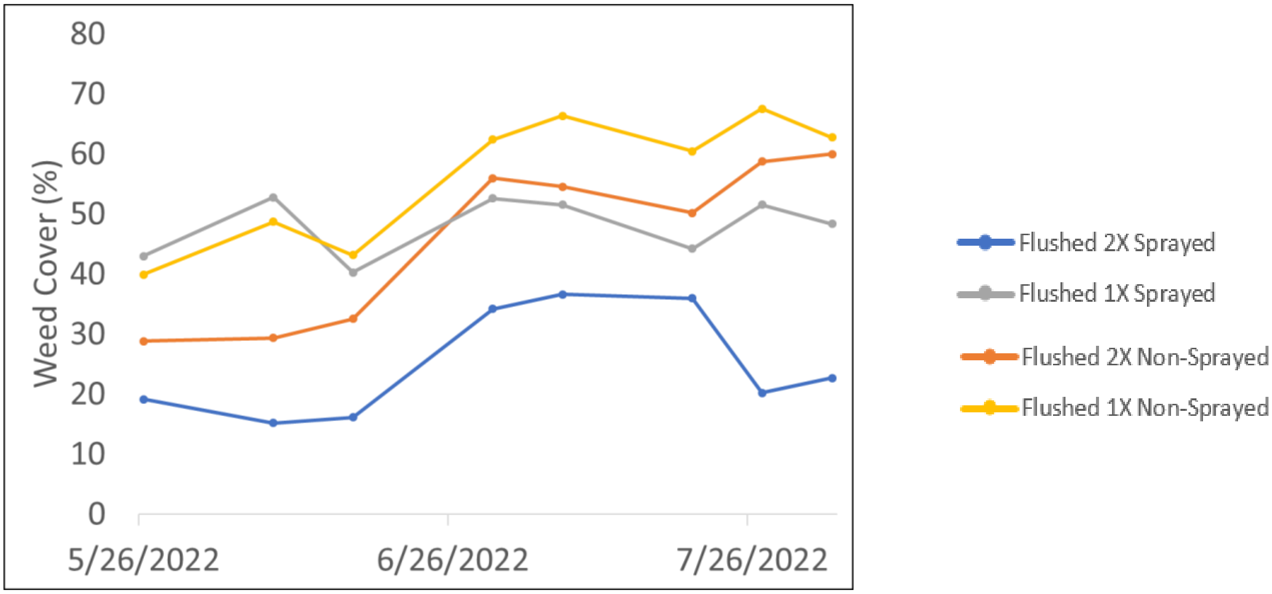

Figure 2. *Percent cover of non-rice weeds in 2022, at approximately 1 month, 2 months, and 3 months after initial water application to the field.*

2.2 Weedy Rice Seedbank

Weedy Rice Seedbank

Soil seedbank analysis in 2019 and 2020 has been completed, and the soil seedbank analysis for 2021 is nearing completion at the timing of the writing of this report. Although not analyzed for significance, there are some differences between the treatments, as well as between the biotypes and years (Table 5 and Table 6). This difference is evident even though the amount of plants transplanted and seeds spread of each biotype was constant in 2018-2019 for each basin, plot, and biotype.

Likewise, there is variability within each plot, ranging from north to south (Table 7 and Table 8). The variability is common in weed populations, and reflects the spread of the plants across the field out from the seed sources (mature plants that have gone to seed) as well as the spring tillage, which moves seed around the top 10-15 inches of soil. In the second year, there is significantly more weedy rice seed in all plots in comparison to 2019. There is a very large increase on the north end of the Stale Seedbed plots, which happens to be the area where the weed emergence counts were taken.

Table 5. *Weedy rice seeds (adjusted to seeds per 1000 cm^3 of soil) per treatment per biotype, averaged across the 150 ft (39 m) long plots and three replications (plots) per basin per biotype in 2019. "Type" = biotype in the table.*

	Seeds per 1000 cm^3		
Type	**Control**	**Rotation**	**Stale Seedbed**
1	0.2	1.1	1.0

2	1.2	1.1	1.2
3	0.3	1.4	1.2
5	1.9	0.8	0.5

Table 6. *Weedy rice seeds (adjusted to seeds per 1000 cm^3 of soil) per treatment per biotype, averaged across the 150 ft (39 m) long plots and three replications (plots) per basin per biotype in 2020. "Type" = biotype in the table.*

	Seeds per 1000 cm^3		
Type	**Control**	**Rotation**	**Stale Seedbed**
1	4.7	2.9	5.1
2	3.0	1.5	3.7
3	3.9	2.4	4.1
5	4.8	2.5	3.8

Table 7. *Weedy rice seeds (adjusted to seeds per 1000 cm^3 of soil) per treatment per biotype, averaged across the 150 ft (39 m) long plots and three replications (plots) per basin per biotype in 2019. "Type" = biotype in the table.*

	Seeds per 1000 cm^3											
Transect	**Control**				**Rotation**				**Stale Seedbed**			
m from North	**Type 1**	**Type 2**	**Type 3**	**Type 5**	**Type 1**	**Type 2**	**Type 3**	**Type 5**	**Type 1**	**Type 2**	**Type 3**	**Type 5**
3	0.0	0.0	0.0	0.0	1.3	0.7	1.7	1.3	0.7	3.0	4.4	1.0
9	0.3	0.3	0.3	0.0	0.5	1.3	0.7	1.3	3.0	2.0	0.7	1.0
15	0.0	0.3	0.7	1.0	0.3	0.0	0.0	1.0	0.0	0.7	0.0	0.0
21	0.7	0.3	0.3	0.7	0.0	0.7	0.7	1.0	0.7	0.3	1.7	0.3
27	0.3	0.0	0.0	0.3	1.5	0.3	0.3	1.3	0.0	0.7	0.0	0.0
33	0.3	0.3	0.0	1.0	1.3	1.0	0.7	1.7	2.0	1.3	1.0	0.0
39	0.3	0.7	0.3	1.0	1.3	1.3	3.4	3.7	0.3	0.0	0.3	0.0

Table 8. *Weedy rice seeds (adjusted to seeds per 1000 cm^3 of soil) per treatment per biotype, averaged across the 150 ft (39 m) long plots and three replications (plots) per basin per biotype in 2020. "Type" = biotype in the table.*

	Seeds per 1000 cm^3											
Transect	**Control**				**Rotation**				**Stale Seedbed**			
m from North	**Type 1**	**Type 2**	**Type 3**	**Type 5**	**Type 1**	**Type 2**	**Type 3**	**Type 5**	**Type 1**	**Type 2**	**Type 3**	**Type 5**

3	9.1	4.0	6.1	2.4	3.7	5.4	3.0	2.4	6.7	11.1	8.1	2.7
9	2.7	3.0	4.0	5.4	3.7	5.7	6.7	5.7	19.9	9.8	10.4	6.7
15	2.7	5.1	1.3	2.4	1.7	3.0	4.4	1.3	2.0	1.0	2.4	5.1
21	0.0	0.0	3.4	4.4	1.7	2.0	0.7	0.7	3.0	0.7	0.7	2.4
27	3.0	0.3	2.0	5.1	1.0	3.7	1.7	2.0	1.7	0.7	2.7	3.4
33	1.7	1.3	1.7	2.4	4.0	1.7	3.0	1.0	1.3	2.4	2.4	2.7
39	0.7	2.7	0.7	3.7	1.7	2.4	0.7	1.0	1.0	0.3	2.0	1.7

2.3 Over-Wintering Experiment

Over-Wintering Experiment

The research is taking place outdoors over the winter (October through March) at a fenced site on Colusa County property, in Colusa, CA. The experiment began in the fall of 2019, and the first year finished in the spring of 2020. It was repeated in the winter of 2020 through the spring of 2021, and again in 2021-2022. Since winter flooding in the field is not possible, the experiment was set up in wading pools, similar to a recent experiment that Luis Espino and Larry Godfrey conducted on an invertebrate, soil-borne pest, tadpole shrimp (unpublished data). Homogenized rice-field soil was placed about 6 inches deep into the tubs.

The experiment was set up as a Randomized Complete Block Design (RCBD). The two main-plot treatments to be tested are as follows:

1) Control: ambient winter conditions;
2) Flooding: flooded to 3-4 inches above the soil surface in October, and maintained through February

In November 2019, 100 seeds of weedy rice biotypes 1, 2, 3, and 5 were buried in mesh bags, at two depths: at the soil surface and buried approximately 6 cm deep. M-206 was also utilized as a control. In total, there were eight replications of each treatment and depth, of each weedy rice type as well as M-206. Bags of weedy rice that were not buried in the soil (from the same seed source), were allowed to remain at room temperature in the lab as well and were subjected to the same germination/viability testing. Bags were removed at 1-month intervals: December 2019, January 2020, and February 2020. Removed seeds were placed in an incubator at 30^0 C as soon as they were removed from the soil. They were kept constantly moist, and germination counts were taken at 7 days and 14 days after placement in the incubator. At 14 days, any seeds that had not germinated were assessed for viability and dormancy. Remaining seeds were gently pressed, and if seed contents evacuated from the seed coat, seeds were rated as "dead'. Seeds that did not evacuate from the seed coat were cut in half (lengthwise) and placed in a solution of 1% Tetrazolium. Approximately 24 hours after placement in the solution, seeds were evaluated for staining of the embryo. If the embryo was stained red, seeds were assumed to be viable. Seeds that were still viable after 14 days of incubation, and had not germinated, were assumed to be "dormant".

Results

Over-wintering Experiment (2019-2020)

There were changes over the 3-month period, both in terms of seed viability (germination), death, and dormancy, regardless of the treatment (ambient/control or flooding). Generally, there was an increase in death/dormancy and a decrease in germination. However, there were some differences depending on the weedy rice biotype (Figure 3 and Figure 4). As expected, the M-206 had almost no dormancy, regardless of treatment or time in the soil (Figure 3). Likewise, the germination rate decreased over time and the proportion of dead seeds increased over time, which is consistent with M-206 being a domesticated rice variety (little to no dormancy). Biotype 5 weedy rice, which in previous studies was shown to be most closely related to domesticated California varieties (with low dormancy), showed similar behavior to M-206 (no increase in dormancy over time, increased seed death). Biotype 1 showed increased dormancy over time when buried in the soil at 6-cm, both in the flooded and control (ambient) conditions, as did Biotype 2, but to a lesser degree (smaller percentage of seeds when compared to Biotype 1). Biotype 3 showed an increase in dormancy over time only under control (ambient) conditions when buried at 6-cm. Biotype 1, Biotype 3, and Biotype 5 showed increased mortality over time when buried at 6-cm under ambient conditions. Biotype 2 showed similar mortality under all field conditions over time.

At 90 days after burial (Figure 5, and Figure 6), all of the types had higher mortality under ambient conditions than under flooded conditions. The burial depth did make a difference, however, with seeds buried at 6 cm showing slightly higher mortality for Biotype 1, Biotype 3, and Biotype 5 (under both ambient and flooded conditions). Biotype 2 was the opposite, with mortality being slightly higher when at 2-cm (under both ambient and flooded conditions). Germination was higher when seeds were at the 2-cm depth (across all biotypes, and for both flooded and ambient conditions). Dormancy was higher when seeds were buried at 6-cm, for Biotypes 1, 2, and 3, with slightly higher dormancy under ambient conditions for Biotypes 2 and 3. Biotype 5 had no dormancy, regardless of treatment.

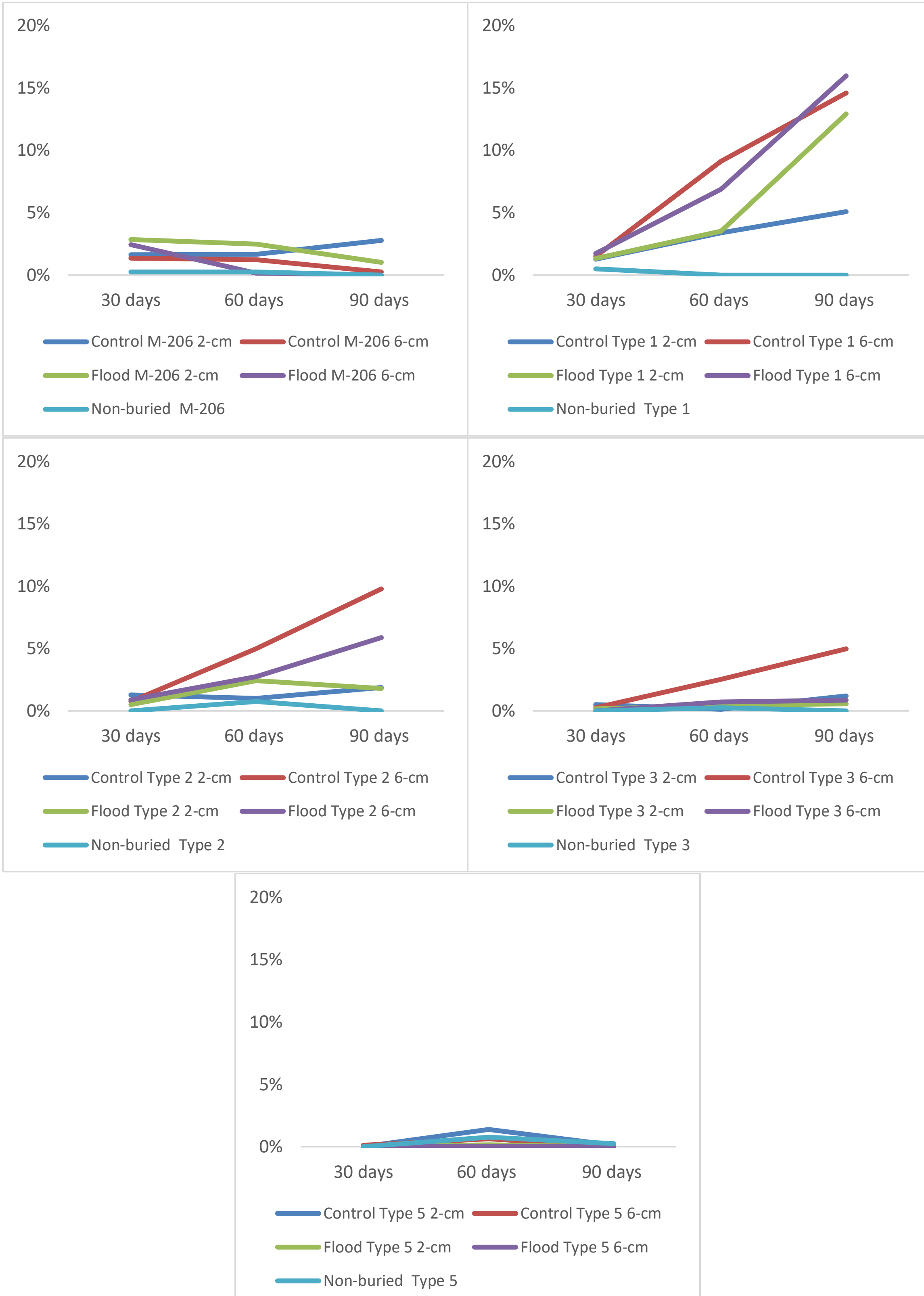

Figure 3. *Average percentage of dormant seeds (over 8 replications per biotype/variety) still viable after 14 days of incubation (subjected to 1% Tetrazolium test), when removed at 30, 60, and 90 days after placement in the soil. "Type" = biotype in the above figure.*

Figure 4. *Average percentage of dead (non-viable) seeds (over 8 replications per biotype/variety) after14 days of incubation when removed at 30, 60, and 90 days after placement in the soil. "Type" = biotype in the above figure.*

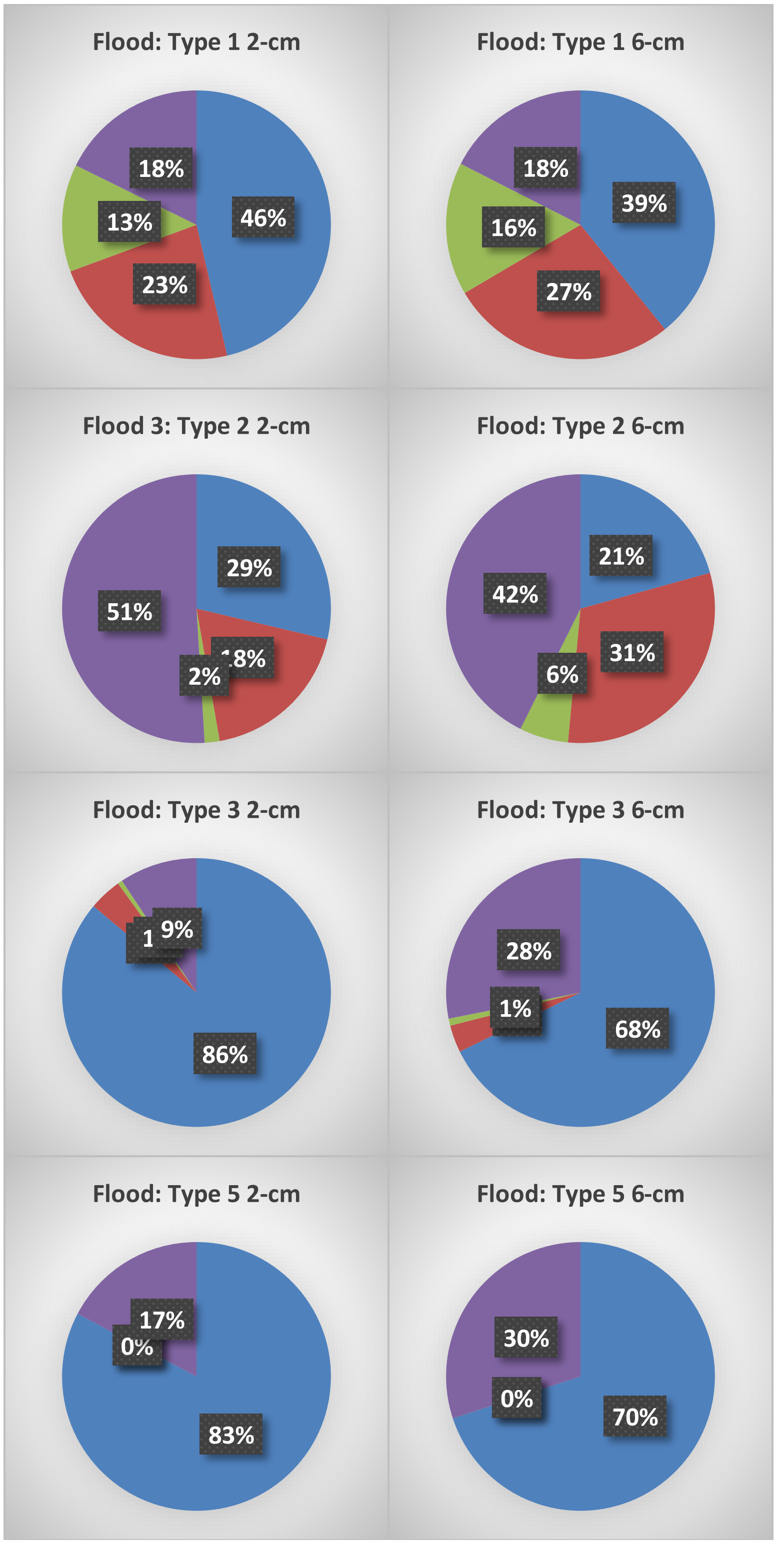

Figure 5. *Percentage of total seeds after 90 days for each weedy rice biotype that was dead (yellow), dormant (grey), germinated after 7 days (blue), and germinated after 14 days (orange) under flooded conditions, buried at 2-cm and 6-cm depth. "Type" = biotype in the above figure.*

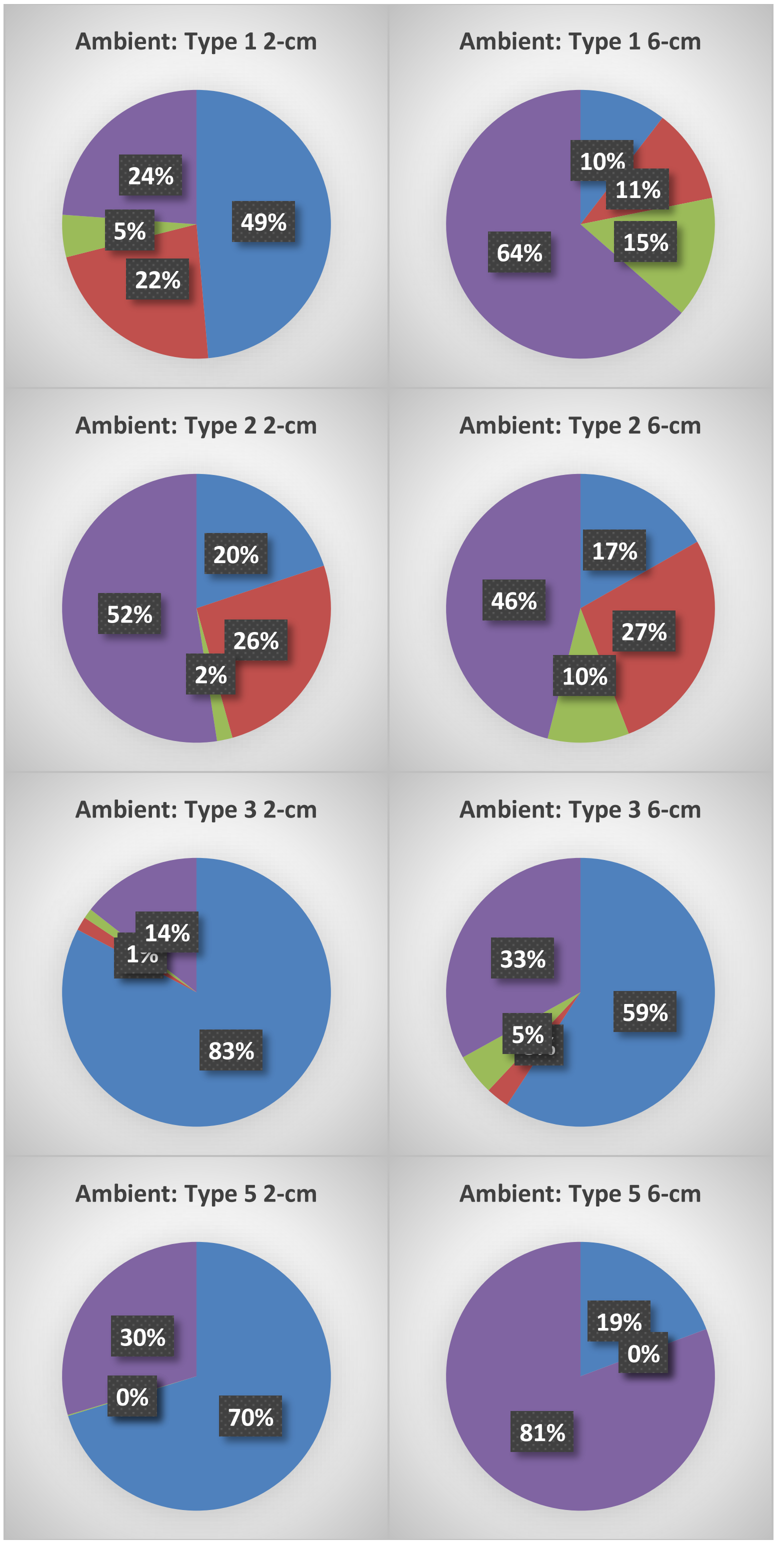

Figure 6. *Percentage of total seeds after 90 days for each weedy rice biotype that was dead (yellow), dormant (grey), germinated after 7 days (blue), and germinated after 14 days (orange) under ambient conditions (control), buried at 2-cm and 6-cm depth. "Type" = biotype in the above figure.*

2020-2021

There were changes over the 3 months, both in terms of seed viability (germination), death, and dormancy, regardless of the treatment (ambient/control or flooding). Generally, there was an increase in death (mortality) as well as dormancy, and a decrease in germination.

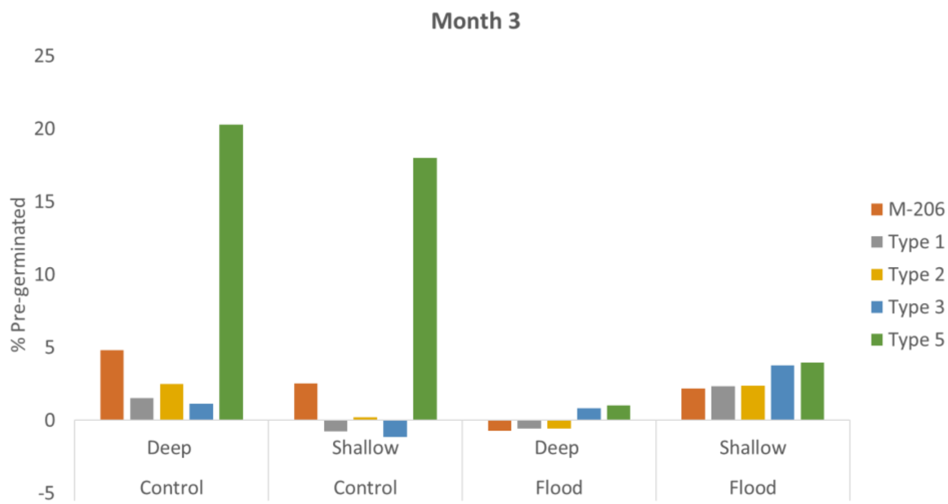

Figure 7. *At 3 months, the number of pre-germinated seeds per biotype/variety (including M-206) and under each treatment, directly after removal from the soil. "Type" = biotype in the above figure.*

One of the most interesting data points was the pre-emergence of weedy rice biotype 5, before removal from the soil in the control treatments (Figure 7). Because biotype 5 has little to no dormancy, this may indicate that for biotype 5, a non-flooded winter field may be the best treatment option, as opposed to flooding. In this scenario, since growers are doing field preparation in April/May using tillage, they would likely till under all of the pre-germinated weedy rice biotype 5. However, biotype 5 is the only biotype that pre-germinated in large numbers, so it would be the only biotype for which this would be an effective control method.

For mortality at the end of the 3 months, it appears that shallowly buried seeds (seeds near the soil surface), had greater mortality than seeds that were buried, across both treatments as well as across both biotypes (Figures 8 to 11). Biotype 3 had the lowest mortality rate, which means that most of the seed was either viable or dormant. This correlates well with what we have seen of Biotype 3's persistence in the field (some fields have been infested for 10 or more years). For Biotype 1 and Biotype 5, non-flooded (ambient) conditions proved to be most effective at causing mortality, whereas, for the other types (Biotype 2 and 3), there were no large differences between the flooded and control treatments.

Evidence from the southern United States found that weedy rice seeds under flooded winter conditions showed greater mortality than those under ambient conditions. The difference between the two locations could be because, in California, winter conditions generally involve rain, so even fields that are not purposefully flooded often are waterlogged. However, further investigation is necessary to be able to draw conclusions from the data. We hope to have information related to weather (rain and temperature patterns) which will give a better idea of the correlation (or lack thereof) between moisture and seed mortality.

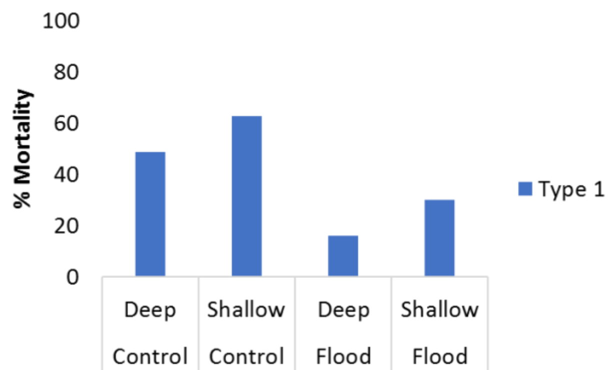

Figure 8. *Percent mortality under each treatment at 3 months after burial for weedy rice biotype 1, after 14 days of incubation. "Type" = biotype in the above figure.*

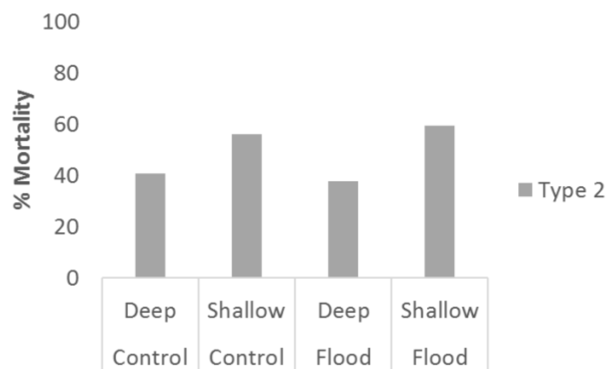

Figure 9. *Percent mortality under each treatment at 3 months after burial for weedy rice biotype 2, after 14 days of incubation. "Type" = biotype in the above figure.*

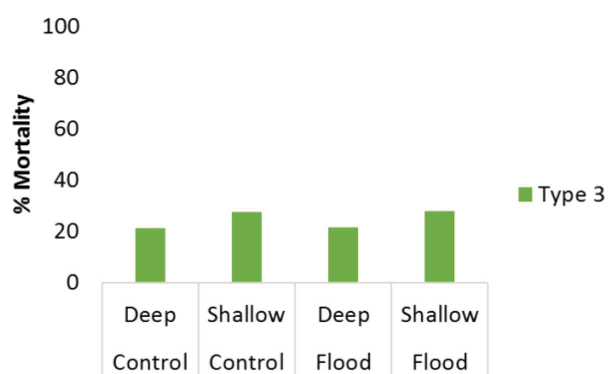

Figure 10. *Percent mortality under each treatment at 3 months after burial for weedy rice biotype 3, after 14 days of incubation. "Type" = biotype in the above figure.*

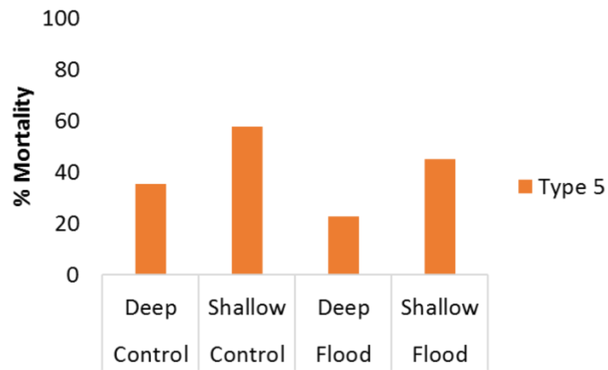

Figure 11. Percent mortality under each treatment at 3 months after burial for weedy rice *biotype 5, after 14 days of incubation. "Type" = biotype in the above figure.*

Objective: To test the new biotypes found in 2018-2020 for shattering and dormancy

3.1

In 2018, we found Type 6, and in 2019, we found Type 7. In 2021, we found at minimum 3-4 other possible types (at least one of which appears to NOT have a red pericarp). To confirm weediness (not just red pericarp), it is important to grow the samples out in the greenhouse to test for shattering and dormancy. The preliminary identification of Type 6 and Type 7 was made by field and greenhouse observations and was not replicated or carried out in a strictly scientific manner.

In 2022, we tested 17 suspicious samples: submitted by growers, collected by PCAs, by the UCCE Rice Team, and by Timothy Blank. Most samples were from one location only, meaning that they are likely low-acreage infestations at this time. However, there was one type that was found in two counties, at two different grower fields, and in multiple checks or fields at those ranches All were tested against known weedy rice samples, California japonica varieties, and some specialty varieties. At this time, we have conducted 2 replications thus far, so results are preliminary (see APPENDIX I for details of each type).

At this point, it appears that we have several likely new biotypes (8 out of the 17 tested), two of which are white-pericarped. In the next year, once we have completed the third replication, we will begin to disseminate information to growers, PCAs and other stakeholders regarding the new types, their identification, and distribution.

Objective: To finalize analysis of field data from years 2018-2021

4.1 The final data analysis was not completed in 2022, we are still working on it, but our results for the overwintering data will be completed this year. Likewise, we hope to complete the data analysis for the emergence experiments that took place at UC Davis as well, in 2023.

Objective: To disseminate pertinent results and best management practices to rice growers and other stakeholders

5.1 Publications and Media. Throughout the 2016-2022 seasons, several extension publications were published through several different channels, including an identification brochure and poster, which were published with the assistance of the California Rice Commission (CRC). Likewise, a weedy rice-specific website, www.caweedyrice.com was also launched at the beginning of the 2017 season (with the CRC). Two videos were created and published on YouTube with the assistance of the CRC: both were focused on weedy rice identification in the field. UCCE launched a weedy rice-specific email listserv, which provided periodic updates of research and other information pertinent to weedy rice, over the course of the 2017 through 2021 seasons. A Weedy Rice Reporter App (for iOS and Android) was developed to allow reporting of weedy rice infestations. In 2017-2022 several blog posts were published on the UCCE Rice blog, as were several updates in the UCCE County Newsletters. There have also been several trade journal articles published in CAPCA Adviser. In 2021, a video series on the identification of each Biotype 1 to 5 was completed and will be published on the UC Rice YouTube Channel. Two UC FactSheets will also be completed this year. An ArcGIS Story was created in 2021 by Luis Espino, Timothy Blank, and Whitney Brim-DeForest: https://storymaps.arcgis.com/stories/e60e7e3405744485943fa54418087d9c

5.2 Meetings and Field Days. Our UCCE Winter Rice Grower Meetings featured one talk on weedy rice in January 2017, two talks in January 2018, one talk in January 2019, one in 2020, and one in 2021, and one in 2022. A weedy rice table with plants and other materials was displayed from 2016-2019 and again in 2021-2022 at the Rice Experiment Station's Annual Rice Field Day. The Rice Weed Course featured one talk on weedy rice in 2019, and a weedy rice identification interactive session as well, both of which were repeated in 2021. In 2017, Luis Espino and Whitney Brim-DeForest held three weedy-rice-specific workshops. We held two in 2019, and another in 2021. One was invitation-only, and representatives from all rice-breeding facilities in California were invited to discuss the genetics of weedy rice, as well as means of preventing the importation of new weedy rice plants into California. A second workshop, open to the public, was held to update growers and PCA's on research and identification for weedy rice in California. In 2020, two virtual updates were given, one at the Virtual Rice Field Day (125 attendees), and one at the Sacramento Valley CE Webinar (65 attendees). The videos from the virtual field days are published on YouTube for viewing. Espino and Brim-DeForest held two "pop-up" field days in 2020, with about 40 total attendees. In 2022, we held a series of 10 trainings across the Sacramento rice-growing region for PCA's as well as county Ag Biologists, to train them on weedy rice management and identification.

PUBLICATIONS OR REPORTS:

- De Leon, Teresa; Karn, Elizabeth, et al. (2019). Genetic variation and possible origins of weedy rice found in California. *Ecology and Evolution*. 9:10, 5835-5848.
- Karn, E., De Leon, T., Espino, L., Al-Khatib, K., & Brim-DeForest, W. (2020). Effects of competition from California weedy rice (*Oryza sativa* f. *spontanea*) biotypes on a cultivated rice variety. *Weed Technology*, 1-9. doi:10.1017/wet.2020.35

- Karn, E., De Leon, T., Espino, L., Al-Khatib, K., & Brim-DeForest, W. (2020). Phenotypic Diversity of Weedy Rice (*Oryza sativa* f. *spontanea*) Biotypes Found in California and Implications for Management. *Weed Science*, 68(5): 485-495.
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Popular press articles:

- Brim-DeForest, W (2018). What Makes a Weed a Weed? The Case of "Weedy" Rice. *UC Weed Science Blog.* January 8, 2018.
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- Brim-DeForest, W; Espino, L; Blank, T (2019). Weedy Rice: 2018 season wrap-up and looking ahead for 2019. *Rice Notes Newsletter.* March.
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- Brim-DeForest, W. and Espino, L. (2020). Weedy Rice Update. California Rice Research Board Newsletter Issue 40: Winter 2020.
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- Brim-DeForest, W., Johnson, T. (2021). Growers Should Consider Fallowing Worst Weedy Rice Fields This Year. CalRiceNews.org: April 15, 2021

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- Brim-DeForest W, Espino L, Clark T, Blank T. (2021). Survey of California weedy rice (Oryza sativa f. spontanea) acreage: infestation patterns and severity. *Report to California Rice Commission.*
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- Brim-DeForest, W; De Leon, T; Al-Khatib, K (2018). Effects of Weedy (Red) Rice Competition on Early Growth and Yield of California Medium-Grain Rice. *In Proceedings of the 37th Rice Technical Working Group*. Long Beach, CA. 19-22 February 2018.
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- De Leon, T; Al-Khatib, K; Blank, T; Espino, L; Mutters, RG; Leinfelder-Miles, M; Linquist, BA; Brim-DeForest, WB (2018). Morphological and Physiological Characterization of California Weedy Rice. *In Proceedings of Weed Science Society of America Annual Conference*. Arlington, VA. 29 January - 1 February, 2018.
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- Brim-DeForest, W; Espino, L; Linquist, B; Leinfelder-Miles, M; Mutters, RG; Al-Khatib, K (2018). Weedy Rice in California: Lessons Learned in Research and Extension. *In Proceedings of Weed Science Society of America Annual Conference*. Arlington, VA. 29 January - 1 February, 2018.
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- Karn E, Bhagirath S, Espino L, Brim-DeForest W. (2020). Survey of Rice Growing Practices in California Identifies Perceptions and Management of Weeds and Weedy Rice. *In* Proceedings of Weed Science Society of America Annual Conference, 2-5 March 2020 Maui, HI.
- Galvin LB, Mesgaran MB, Brim-DeForest W, Al-Khatib K. (2020). Burial Depth and Flooding Effects on Emergence of Five California Weedy Rice (Oryza sativa f. spontaneae Rosh.) Accessions. *In* Proceedings of Weed Science Society of America Annual Conference, 2-5 March 2020 Maui, HI.
- Brim-DeForest W**,** Espino, L. (2020). Weedy Rice (Oryza sativa f. spontaneae) Emergence and Growth Under Variable Irrigation Practices. *In* Proceedings of Weed Science Society of America Annual Conference, 2-5 March 2020 Maui, HI.
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- Galvin LB, Brim-DeForest W, Al-Khatib K. (2020). Thermal Time to Emergence of California Weedy Rice (Oryza sativa f. spontanea) Under Flooded Field Conditions: A 2-year Study. In Proceedings of Weed Science Society of America Annual Conference, 15-19 February 2021, Virtual.

AWARDS:
The paper entitled "Phenotypic Diversity of Weedy Rice (*Oryza sativa* f. *spontanea*) Biotypes Found in California and Implications for Management." was selected as the "Outstanding Paper of the Year" by the Weed Science Society of America, for the journal *Weed Science* for 2020.

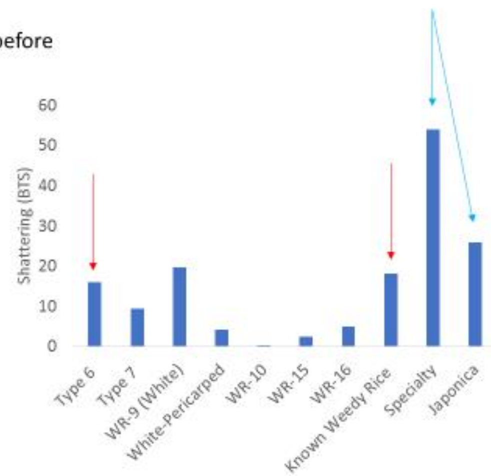
GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:
The past five seasons of work on the weedy rice populations in California yielded information regarding the number of weedy rice populations as well as the approximate distribution of those populations. In the past 5 years, we have identified over 13,000 infested acres and 7 biotypes, with several new biotypes confirmed in 2022. Genetic analysis confirmed that the five biotypes discovered in 2016 were genetically and morphologically distinct from one another. Comparison to weedy rice populations from around the world has begun to elucidate the possible pathways for introduction of weedy rice into California, as well as giving insight into prevention of its spread. Information on dormancy and shattering has allowed UCCE advisors to begin to give management recommendations based on which population is found in a field. Competition experiments and growth potential experiments in the greenhouse yielded specific reductions in several yield components, some of which differed between biotypes. In 2018, a preliminary drone flight with the IGIS Center at UC Davis was not able to distinguish between rice, weedy rice, and other weed species, including watergrass. Work continued in 2019 with the drones, but results were shared in the report entitled "Evaluating the potential for aerial imagery in detecting weedy rice in California rice fields". We have completed two years of field studies which show population dynamics and emergence of weedy rice under field conditions. The three years of the overwintering experiment showed differences between biotypes in response to winter flooding, as well as impacts of fall tillage. The two years of the fallow experiment at UC Davis appears promising in effectively controlling weedy rice with a managed fallow. Our extension program has reached approximately 3,000 growers, PCAs, and county agricultural biologists. Effective teamwork with the rice industry enabled information to be passed on to as many stakeholders as possible, through a variety of publication and meeting formats.

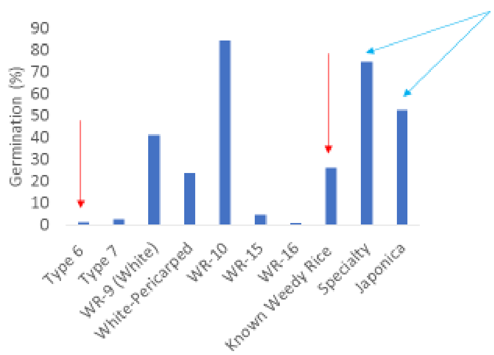
In 2022, we conducted the second year of the fallow experiment, determining that no weedy rice emerged under any treatments. This indicates that utilizing a managed fallow might be an effective treatment to manage weedy rice, if the weedy rice is not allowed to go to seed. Out of the possible new biotypes tested 8 appear to be weedy, and dissimilar phenotypically from the previously-identified weedy rice types. The results of the overwintering experiment indicate that zero fall tillage should be a recommended management practice, to lessen the number of seeds that survive over the winter. Winter flooding, however, does not necessarily increase seed mortality.

APPENDIX I

Type 6

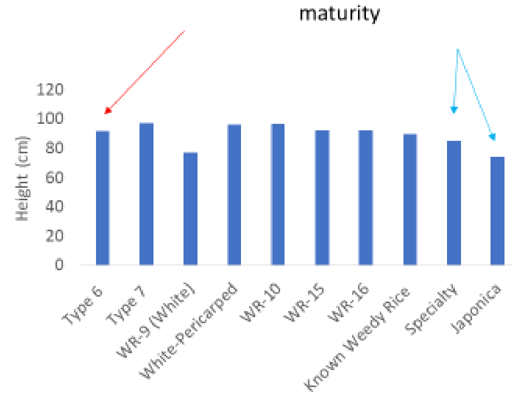
- Black-hulled
- Long awns
- Awns reddish before maturity





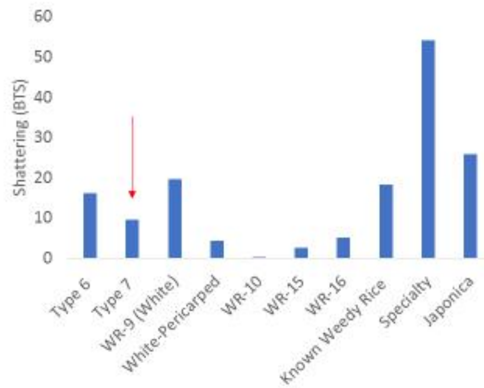
Type 6

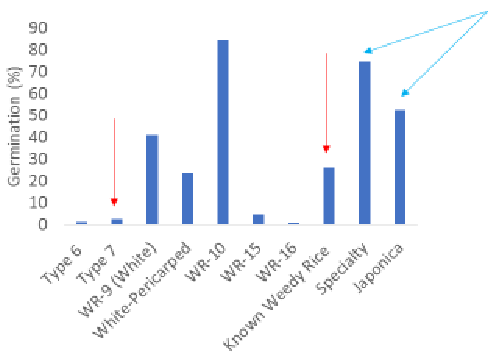
- Black-hulled
- Long awns
- Awns reddish before maturity



Type 7

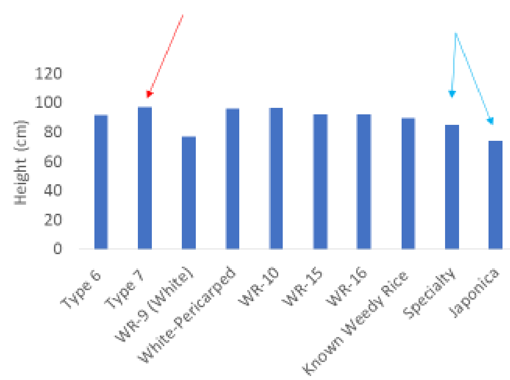
- Straw-hulled
- Long awns
- Awns are red before maturity



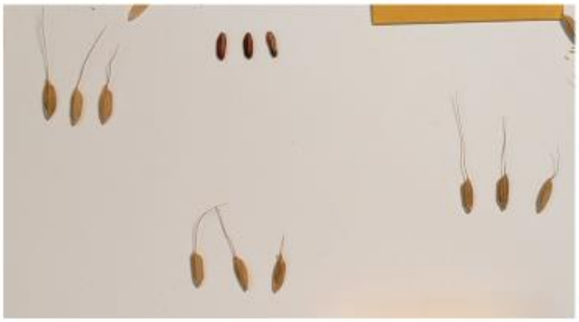


Type 7

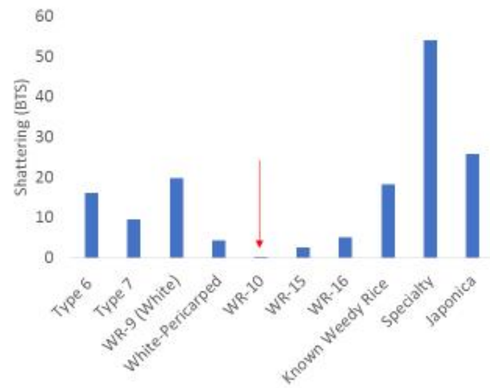
- Straw-hulled
- Long awns
- Awns are red before maturity

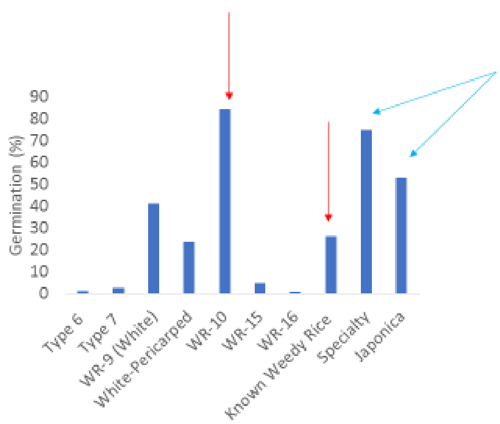


WR-10



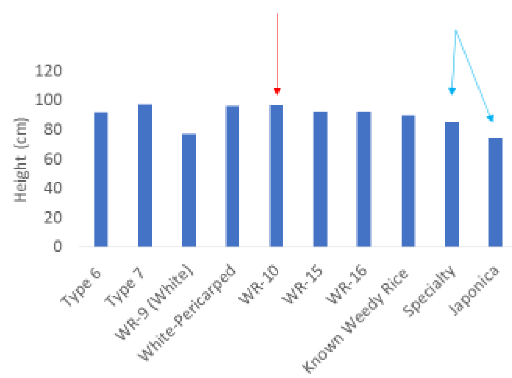
- Straw-hulled
- Medium length awns
- Seed is closer in size to a long-grain





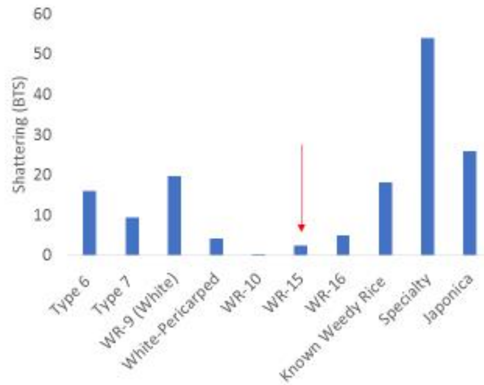
WR-10

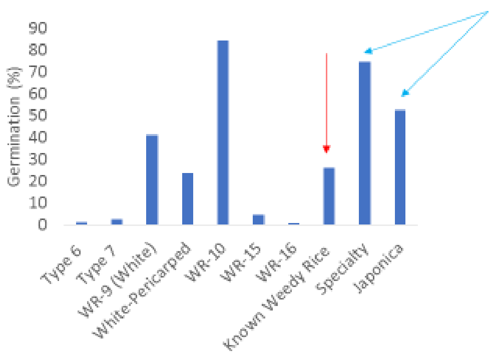
- Straw-hulled
- Medium length awns
- Seed is closer in size to a long-grain



WR-15

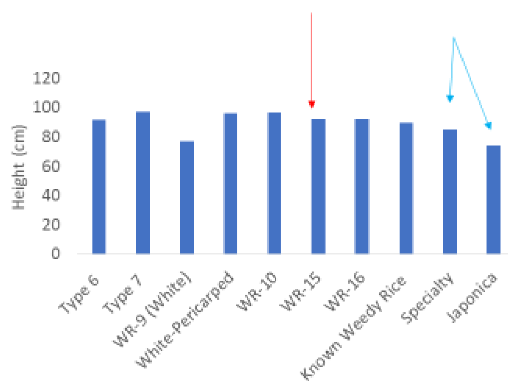
- Variant of Type 3?
- Awns not exactly the same





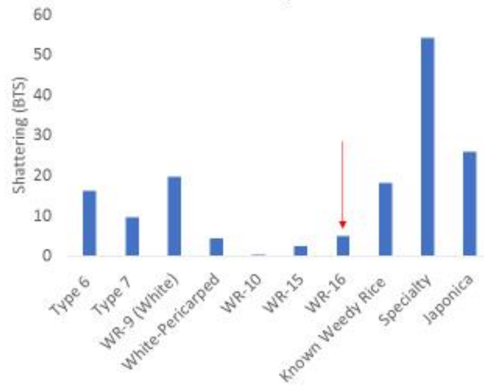
WR-15

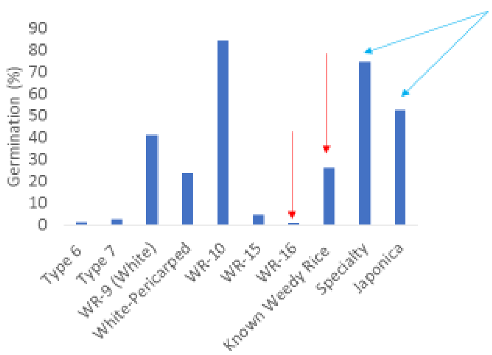
- Variant of Type 3?
- Awns not exactly the same



WR-16

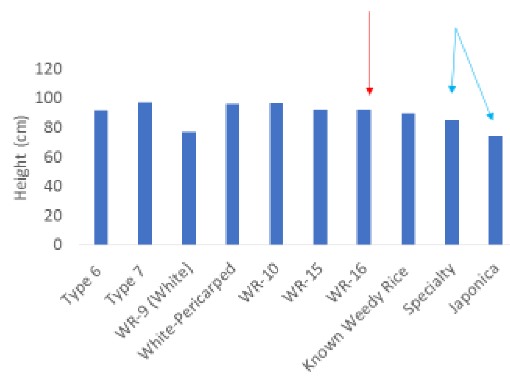
- Black-hulled
- Long awns
- Awns NOT reddish before maturity





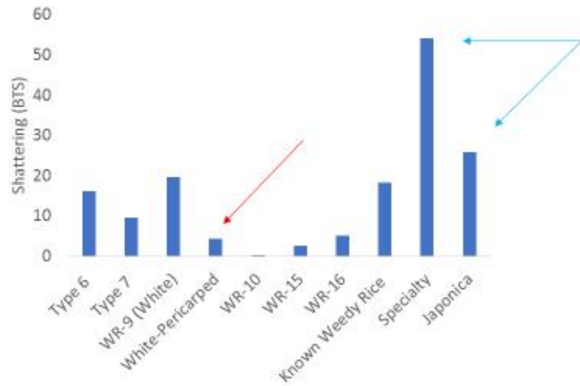
- Black-hulled
- Long awns
- Awns NOT reddish before maturity

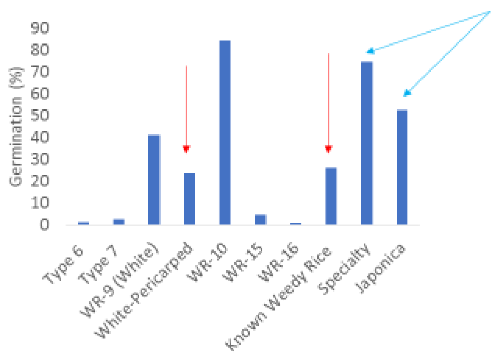
WR-16



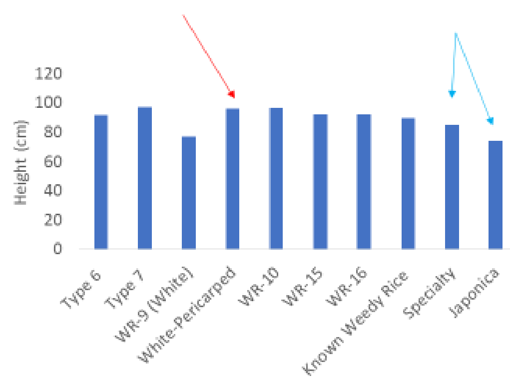
White Pericarped (multiple samples, 2 sites)

- Straw-hulled
- Long awns
- Awns reddish before maturity
- WHITE pericarped



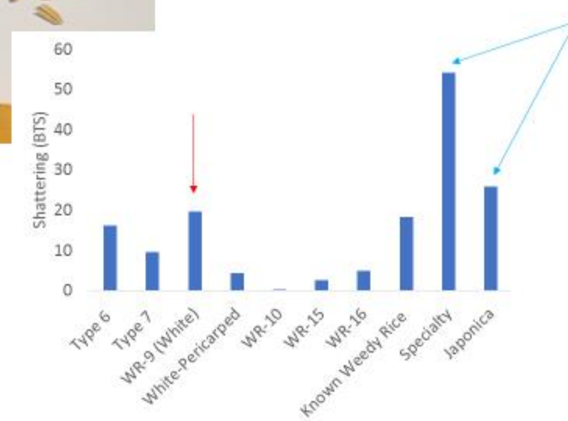


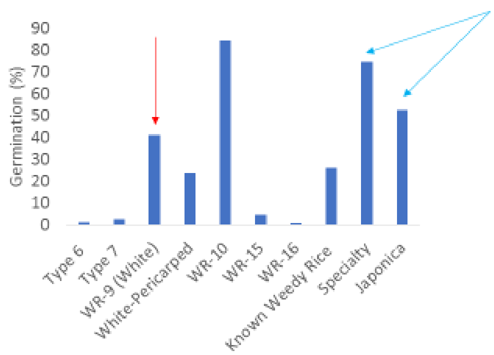
- Straw-hulled
- Long awns
- Awns reddish before maturity
- WHITE pericarped



WR-9

- Straw-hulled
- Short awns
- WHITE pericarped





WR-9

- Straw-hulled
- Short awns
- WHITE pericarped