Germination behaviour of red rice (*Oryza sativa* L.) seeds in field and laboratory conditions

Francesco VIDOTTO*, Aldo FERRERO

Dipartimento di Agronomia Selvicoltura e Gestione del Territorio, Università degli Studi di Torino,
Via Leonardo Da Vinci, 44, 10095 Grugliasco (TO), Italy

(Received 7 February 2000; revised 4 April 2000; accepted 6 April 2000)

Abstract – Two experiments were carried out in 1996–1998 to study (1) the germination behaviour of red rice seeds kept for different periods of time in field and laboratory conditions, and (2) the weed emergence behaviour in response to different burial depths. The first experiment was carried out considering mature red rice seeds of two biotypes which were exposed to field conditions and to 20 °C, for different periods of time, and then tested for their germinability over 6 months. The time required for red rice seed to germinate in petri dishes depended on the storage conditions and proved to be inversely related to the storage duration. Immediately after harvesting, the red rice seeds required 180 days of permanence in petri dishes to germinate. This time was reduced to 20 days when the seeds were exposed for 30 days at 20 °C or for 160 days in field conditions. The second experiment was conducted both in the greenhouse and in the field, placing seeds at different depths from 0 to 13 cm, in saturated and flooded soil conditions, and in loamy and clayey soil. The emergence was affected both by the depth of burial and the presence of a water layer on the soil surface, and occurred from a maximum depth of 10 cm. Most of the emergences were recorded in the 0–5 cm soil layer in saturated loamy soil (92–45%).

rice / red rice germination / red rice emergence / weed

Résumé – Germination de graines de riz rouge (*Oryza sativa* L.) en conditions de plein champ et de laboratoire. Le but de ce travail, réalisé de 1996 à 1998 était l'étude (1) de la germination des graines de riz rouge soumis en fonction des conditions de stockage et (2) de la capacité germinative à différentes profondeurs d'enfouissement. La première étude a consisté à soumettre des graines de riz rouge mures de deux biotypes à des conditions de plein champ et à 20 °C pendant des périodes de différentes durées. On a ensuite testé leur capacité germinative pendant six mois. Le temps nécessaire à la germination du riz en boîtes de Petri dépendait des conditions de stockage et, en particulier, était inversement proportionnel à sa durée. Immédiatement après la récolte, le temps nécessaire à la germination des graines était de 180 jours. Dans la deuxième étude, réalisée en serre et en plein champ, on a enfoui des graines de 0 à 13 cm dans un sol

Communicated by Gérard Guyot (Avignon, France)

* Correspondence and reprints
vidotto@agraria.unito.it

limoneux et un sol argileux inondés ou saturés d'eau. L'émergence dépendait soit de la profondeur de l'enfouissement et de la présence d'une nappe d'eau à la surface du sol et avait lieu seulement à partir d'une profondeur maximum de 10 cm. Dans la plupart des cas, l'émergence était observée à partir de la couche 0–5 cm dans un sol limoneux saturé (92–45 %).

riz / germination du riz rouge / émergence du riz rouge / adventice

1. Introduction

Red rice (*Oryza sativa* L.) is a troublesome weed that infests most rice growing areas throughout the world [16, 22]. This weed is characterised by a wide variability of anatomical and biological traits [5, 19], even though it shows a high similarity with cultivated rice varieties, in particular in the early growth stages. The caryopsis usually has a pigmented pericarp, which can be removed with an extra milling that results in broken grains and grade reduction [6, 7, 28].

Weed control strategies are mainly based on a combination of preventive, cultural and chemical practices, with the objective of reducing the weed seed content in the soil [11, 15, 30]. Preventive methods alone are often inadequate, as it is difficult to obtain rice seed that is completely free from weed grains. Cultural and chemical practices are commonly applied, turning rice to rotational crops adopting the false seeding technique. Rotation is frequently the best way to reduce severe red rice infestations but cannot be adopted in saline and hydromorphic soils [2, 26]. The false seeding technique is commonly applied in continuous rice cultivation by stimulating red rice germination with field flooding and spraying systemic herbicides before crop planting.

The successful application of these measures greatly depends on the number of plants which are able to emerge and that can be destroyed with herbicides both in rotational crops and in rice monoculture.

Many weed species normally emerge during a specific period of the year [9, 21, 23]. This behaviour is mainly influenced by seed cultural

practices, environmental conditions and dormancy status [14, 25]. In cropping systems it has been observed that, in general, the ability of weed seed to germinate is affected by the depth at which seeds are buried, in consequence of different soil tillages [24]. It has also been demonstrated that the emergence, in relation to the burial depth, mainly depends on the differences in moisture content, aeration, light availability and temperature within the soil profile, and varies according to the species [3, 17, 29] and the seed size [18]. Soil water moisture also modifies the germination and emergence times within a season. Grain dormancy may depend on physiological (embryo immaturity, endogenous germination inhibitors), mechanical (impermeable seed coats) and environmental factors [27]. It has been demonstrated that red rice, like domestic rice, is mainly influenced by environmental factors, such as temperature, moisture, oxygen and weak acids [4, 13]. In some experiments, complete dormancy breaking occurred within 4–6 weeks after-ripening at 20 or 30 °C, while at 5 °C, this time was dependent on the time allowed to attain safe storage moisture at 20 °C [4]. Leopold et al. [20] found, in red rice seeds stored at –15 °C, that the break of dormancy is very low for moisture contents higher than 18% and lower than 5%. There is however a lack of information on red rice germination after shattering in field conditions, as most studies on dormancy of this weed have been conducted in controlled environmental conditions [8, 12, 20].

The objectives of this study were to evaluate the time required for germination of red rice seeds kept for different periods of time in field and laboratory conditions and to determine the weed emergence behaviour in response to different burial depths.

2. Materials and methods

2.1. Experiment 1 – germination, as affected by the time elapsed after shattering

The study was conducted in the 1996–1998 period. Red rice seeds were collected from mature panicles in naturally infested fields located in the Vercelli area (N.W. Italy), in September 1995 and 1996. Two awnless biotypes were considered in both years. One biotype (EA) came from a paddy cultivated for 6 years with an early long-grain variety (cv. Ariete) and was characterised by a short cycle, tall size and dark panicle. The second biotype (LA) came from a late round-grain variety (cv. Elio) and showed a long cycle, small size and straw-coloured panicle. About 3 kg of seeds of each biotype were harvested by hand-shattering in each year. Intact seeds of both biotypes were immediately broadcast by hand on a rice field area free from red rice, in which the straw was previously removed. Afterwards, the seeded area was covered by a net placed about 15 cm over the soil surface, in order to avoid bird predation. Some other intact seeds were dried at 20 °C on open trays in the laboratory for 7 days and then stored in sealed glass jars at 20 °C. The seed moisture content remained constant (12–13%) during storage. Samples of 500 seeds for each biotype were randomly taken from the field at variable intervals of time. The samplings were carried out up to 215 days from the seed distribution, with samples being picked weekly during the first 70 days and every 14 days (from the 70th to the 124th). Two additional samplings were made on the 183rd and 215th days. Subsamples of 100 seeds each were randomly taken from the 500-seed samples in order to obtain replicates for the germination test, which started within a day of each collection. Germination tests were performed in glass petri dishes in darkness at a constant temperature of 25 °C. Germination tests had a 6 month duration, to cover the whole period in which germination in the field could occur. The germinated seeds were counted each day during the first 20 days and then weekly till the end of the test. The germination tests were also performed each year on seeds of

each biotype stored at 20 °C. In this case, the germinability was assessed at 0, 15, 30 and 70 days after the collection. Regression analysis was performed considering the time (in days) of exposure to field conditions (as the independent variable) and the time of exposure to petri dish conditions needed to reach the maximum level of germinability (as the dependent variable).

2.2. Experiment 2 – emergence from different soil depths

This study was conducted in the greenhouse and the field.

The greenhouse study consisted of two sets of experiments carried out in 1996 and 1997 at the experimental station of Carmagnola (Turin). In all the experiments, red rice emergence was tested, placing seeds in pots (15 × 15 × 18 cm) at 0, 2, 4, 6, 8, and 10 cm of depth, both in saturated and in flooded conditions. In 1996 the experiment was conducted twice (in October and December) in loamy soil (34.8% sand, 59.9% silt, 5.4% clay). In 1997 the experiment was conducted once, in loamy and clayey (15.3% sand, 59.5% silt, 25.2% clay) soil. The pots were placed in tanks in which the water level was maintained at either 4–5 cm over the soil level, in the case of a flooding condition, or at the same level of the soil, in the case of a saturated condition. Each pot was planted with 200 weed seeds at one of the considered depths. The red rice seeds were collected and stored at room temperature in the year preceeding that of the experiment. Germinability of the seeds was tested in glass petri dishes at a constant temperature of 25 °C prior to the start of the trial.

During the experimental period, the air temperature in the greenhouse ranged from 15 to 21 °C. In the 1996 experiment, the red rice seedlings that emerged from each pot were counted daily until 60 days after the beginning of the trial. The experimental design was a split-plot with 4 replicates. The main treatment was the water level (flooded and saturated), and the subplots were the seeding depths.

The field trial was conducted in a loamy soil, during 1998 at Mortara in a rice field free from red rice. In this trial, red rice seeds were placed at 4 depths: 0–1, 4–5, 8–10, and 12–13 cm. As in the greenhouse trial, two water management systems were tested: flooded (with 5–6 cm of water) and saturated conditions. The experimental design was a split-plot with 4 replicates, in which the main plots were subjected to different water management and the subplots to the various seeding depths. The subplots (with a surface of 4 m² each) were planted with red rice seeds in 25 cm spaced lines, with 400 seeds m⁻² density. The counting of the red rice seedlings was carried out 60 days after the sowing.

Analysis of variance was performed on the arcsin transformed data of the emergence percentage.

3. Results and discussion

3.1. Experiment 1 – germination, as affected by the time elapsed after shattering

The results of this experiment pointed out that the ability of red rice seeds to germinate was greatly influenced by the conditions in which the seeds were stored. The data of the two years have been averaged as no year effects were highlighted by statistical analysis for all the considered parameters.

No significant differences were observed between the two considered biotypes. Immediately after collection from the mature panicles, as reported in Figure 1, the seeds showed the first germination only after 165 days of continuous permanence in the petri dishes (DPD). After this time, the germination rate rapidly increased, and the percentage of cumulative germination reached its maximum value at 170 DPD (mean $\pm$ standard deviation: 98% $\pm$ 5.6).

The behaviour of the seeds after 15 days from the shattering was quite similar, either when stored at room temperature or exposed to field conditions. The first germinated seeds were observed after 70 DPD and 86 DPD, in the case of storage at 20 °C, and of permanence in the field, respectively. In both cases, after this time, the germination rate increased slowly till 135–140 DPD, and then rose quickly in a few days. As observed for the seeds tested immediately after the collection, the maximum percentage of cumulative germination was reached in both cases after 170 DPD.

The germination pattern was different for the two conservation conditions considering the seeds tested 30 days after the collection. The seeds maintained at 20 °C showed high values of germinability already after 6 DPD (43.7% $\pm$ 14), and reached a percentage that was not significantly different from the maximum value which had already been obtained after 14 DPD. In contrast, the seeds

Figure 1. Cumulative germination percentages of red rice seeds maintained for different periods of time in the field or at 20 °C. A: immediately after harvesting, B: after 15 (dashed line) or 30 (solid line) days of field exposure, C: after 15 (dashed) or 30 (solid line) days of storage at 20 °C. Bars indicate $\pm$ standard deviations.

Figure 2. Relationship between days of exposure to field conditions (DAF) and duration (in days) of germination test (DPD) required to obtain the maximum percentage of cumulative germination. Mean values for the two years. The asterisks and circles refer to the AE and LA biotypes, respectively. $(DPD = -1.59 DAF + 3.2 \times 10^{-3} DAF^2 + 201.4, r^2 = 0.971)$. The dashed lines represent the interval of confidence of the estimated means).

maintained in the field showed a lower germination rate, even though they started to germinate after 6 DPD, and reached the maximum value of germination percentage ($97.5\% \pm 2.5$) after 153 DPD.

These results are in good agreement with the findings of Cohn and Hughes [4] regarding the effect of various storage temperatures on post-harvest dormancy of red rice seeds. Total germinability does not seem to be affected either by the time or the tested storage condition (20 °C or field). No statistical differences were, in fact, observed for all the total germinability values, which showed a mean value of $97.2\% \pm 3.71$. Considering this behaviour, a regression analysis was performed relating the days of exposure to the field conditions (DEF) to the DPD values referring to the highest cumulative germination values (Fig. 2). A quadratic model fits the trend of the variables with a high level of significance ($P(F) < 0.001$). The two considered variables have a high level of correlation, as indicated by the value of the determination

coefficient ($r^2 = 0.971$). The value (201.4) and the significance ($P(F) < 0.001$) of the intercept in this case are relevant in practical terms and indicate that red rice seeds taken from mature panicles and immediately placed in petri dishes require about 200 days to express all their potential germination capacity. Moreover, most of the germination, as reported in Figure 1, occurred at the end of this period and no differences were observed between EA and LA biotypes.

3.2. Experiment 2 – emergence from different soil depths

3.2.1. Greenhouse trial

The germinability of the seeds utilized in this experiment was 94% and 98% in the first and second year, respectively. The two trials conducted in the first year showed similar results. For this reason only their average values are discussed in this paper. The results of the first year showed that the emergence of red rice was significantly affected both by the depth at which it was planted and the presence of the water layer (Fig. 3A). The highest percentage of emergence (50.7%) was recorded in moist soil for the seeds placed on the soil surface. In these water conditions, emergence occurred from seeds placed up to 6 cm, even though the percentage of emergence already fell below 10% for the seeds placed at 4 cm. In flooding conditions, the emergence percentages were always significantly lower, with a maximum of 16% for the seeds placed on the soil surface. In this case, no emergence was recorded from seeds placed below 4 cm. An examination of the non-emerged seeds showed that some of them had in fact germinated, producing elongated coleoptiles which failed to reach the surface. The percentage of these unemerged seedlings on the total unemerged seeds was, in moist soil, 45% at 4 cm, 21% at 8 cm, and 2% at 10 cm, and in flooded soil, 15% at 4 cm, 6% at 8, and 0% at 10 cm.

The results obtained in the second year of the experiment showed similar trends (Figs. 3C and 3D). In this case, the emergences recorded were generally higher, especially for the seeds placed in

Figure 3. Percentage of red rice emergence from different depths, in saturated and flooded conditions. A: greenhouse experiment, first year (mean values of two trials), B: field experiment, C and D: greenhouse experiment, second year. Bars indicate $\pm$ standard deviations.

the upper layers (0 and 2 cm), and the values showed a higher variability. This behaviour can be partly explained by the higher germinability of the seeds used. The emergence rate, as observed in the previous year, was greatly affected by the depth of the seeds, and also in this case notable emergence rates only occurred from seeds placed up to 4 cm deep. On the other hand, the effect of water management was less remarkable. Significant differences for moist and flooded conditions were observed but only for seeds placed on the surface of clayey soil and at 4 cm in loamy soil. As far as the effect of soil texture is concerned, though the mean values of the emergence rates were generally higher in loamy soil, statistical differences were

observed only in flooded conditions for seeds placed at 4 cm.

3.2.2. Field trial

The emergence of red rice seedlings in field conditions showed a behaviour that was similar to that observed in the greenhouse trial (Fig. 3B). The main differences concerned the effect of water management. In saturated conditions, the red rice in fact emerged with roughly the same percentage both from the surface and from 5 cm of depth. Remarkable emergence rates (12.6%) were also recorded from seeds placed at 10 cm, and some seedlings (0.4% of the seeds) were still able to emerge from 13 cm of depth. In contrast, the

emergence rates were significantly lower in the flooded conditions for all the considered depths. In particular, it drastically fell from the surface (50.6%) to 5 cm depth (2.2%). No emergence was recorded from 10 and 15 cm depth.

4. Conclusions

The red rice seeds were not able to germinate immediately after shattering. This condition of dormancy required different lengths of time to be broken, according to the environmental conditions following the shattering. Dried seeds continuously maintained at 20 °C showed fast germination already after 30 days of storage, while in the field, the seeds required about 150 days of exposure to obtain a high germination percentage within the 30 days of the germination test. The relationship between the days of exposure to field conditions and the duration of the germination test to obtain the highest germination percentages is well fitted by a quadratic function. This behaviour is in accordance with the observations showing that red rice is not able to emerge in field conditions just after shattering during the autumn, though temperatures are favourable for germination. The results of the study on the depth of emergence showed that only red rice seeds placed at up to 10 cm of depth were able to give viable seedlings in saturated conditions. The majority of emergence was recorded from the seeds buried in the 5 cm upper layer. Particularly in clayey soil, the presence of a water layer on the soil surface consistently affected the emergence of red rice seeds buried below the first few centimetres of soil. The information acquired in this research could be helpful in planning more cost-effective control practices. For instance, any control measure based on the stimulation of red rice germination before rice planting should be postponed to the springtime and managed in conditions of soil saturation.

Acknowledgements: This study has been carried out with financial support from the Commission of European Communities, Agriculture and Fisheries (FAIR) specifically the RTD programme, CT96-1450,

“Biology and Integrated Control of Red Rice”. It does not necessarily reflect its views and in no way anticipates the Commission’s future policy in this area. The work is attributable in equal part to the authors.

References

- [1] Baker J.B., Sonnier E.A., Shrefler J.W., Integration of molinate use with water management for red rice (*Oryza sativa*) control in water-seeded rice (*Oryza sativa*), *Weed Sci.* 34 (1986) 916–922.
- [2] Català M., Chemical and cultural practices for red rice control in rice fields in Ebro Delta (Spain), *Crop Prot.* 5 (1995) 405–408.
- [3] Chancellor R.J., The depth of weed seed germination in the field, in: *Proc. Br. Crop. Prot. Conf. Weeds*, 1964, pp. 607–613.
- [4] Chon M.A., Hughes J.A., Seed dormancy in red rice (*Oryza sativa*). 1. Effect of temperature on dry afterripening, *Weed Sci.* 29 (1981) 402–404.
- [5] Craigmiles J.P., Introduction, in: Eastin E.F. (Ed.), *Red rice research and control*, Texas Agric. Exp. Stn. Bull., 1978, pp. 5–6.
- [6] Diarra A.R.J., Smith R.J., Talbert R.E., Interference of red rice (*Oryza sativa*) with rice (*O. sativa*), *Weed Sci.* 33 (1985) 644–649.
- [7] Diarra A.R.J., Smith R.J., Talbert R.E., Growth and morphological characteristics of red rice (*Oryza sativa*) biotypes, *Weed Sci.* 33 (1985) 310–314.
- [8] Eastin E.F., Additional red rice research, in Texas, in: Eastin E.F. (Ed.), *Red rice research and control*, Texas Agric. Exp. Stn. Bull., 1979, pp. 30–34.
- [9] Egley G.H., Williams R.D., Emergence periodicity of six summer annual weed species, *Weed Sci.* 39 (1991) 595–600.
- [10] Fay P.K., Olson W.A., Technique for separating weed seed from soil, *Weed Sci.* 26 (1978) 530–533.
- [11] Ferrero A., Finassi A., Vidotto F., Prediction of red rice seedling densities from seed bank, *Meded. Fac. Landbouwwet. Rijksuniv. Gent*, 1996, pp. 1181–1187.
- [12] Footitt S., Cohn M.A., Seed dormancy in red rice, *Plant Physiol.* 100 (1992) 1196–1202.
- [13] Footitt S., Vargas D., Cohn M.A., Seed dormancy in red rice. X. A ¹³C-NMR study of the metabolism of dormancy-breaking chemicals, *Physiol. Plant.* 94 (1995) 667–671.

- [14] Forcella F., Prediction of weed seedling densities from buried seed reserves, *Weed Res.* 32 (1992) 29–38.
- [15] Ghesquière A., Andre F., Feougier G., Braun P., Un riz adventice, in: ITCF (Ed.), *Riz: Du débouché à la culture*, 1995, pp. 41–44.
- [16] Goss W.L., Brown E., Buried red rice seed, *J. Am. Soc. Agron.* 31 (1939) 633–637.
- [17] Grundy A., Mead A., Bond W., Modelling the effect of weed-seed distribution in the soil profile on seedling emergence, *Weed Res.* 36 (1996) 375–384.
- [18] Hoffman M.L., Owen M.D.K., Buhler D.D., Effects of crop and weed management on density and vertical distribution of weed seeds in soil, *Agron. J.* 90 (1998) 793–799.
- [19] Kwon S.L., Smith R.J., Talbert R.E., Comparative growth and development of red rice (*Oryza sativa*) and rice (*O. sativa*), *Weed Sci.* 40 (1992) 57–62.
- [20] Leopold A.C., Glenister R., Cohn M.A., Relationship between water content and after ripening in red rice, *Physiol. Plant.* 74 (1988) 659–662.
- [21] Ogg A.G. Jr., Dawson J.H., Time of emergence of eight weed species, *Weed Sci.* 32 (1984) 327–335.
- [22] Pantone D.J., Baker J.B., Weed-crop competition models and response-surface analysis of red rice competition in cultivated rice: a review, *Crop Sci.* 31 (1991) 1105–1110.
- [23] Rahaman A., James T.K., Patterns of weed seedling emergence in two New Zealand soils, in: *Proceedings 8th EWRS Symposium “Quantitative approaches in weed and herbicide research and their practical application”*, Braunschweig, 1993, pp. 665–672.
- [24] Roberts H.A., Feast P.M., Fate of seeds of some annual weeds in different depths of cultivated and undisturbed soil, *Weed Res.* 12 (1972) 316–324.
- [25] Saavedra M., Garcia-Torres L., Hernandez-Bermejo E., Hidalgo B., Influence of environmental factors of the weed flora in crops in the Guadalquivir valley, *Weed Res.* 30 (1990) 363–374.
- [26] Sagarra J., Importancia del conreu de l’arròs a Catalunya. Produccions i aprofitaments, in: *L’arròs tècniques*, Fundació La Caixa, Amposta, 1987, pp. 7–10.
- [27] Seshu D.V., Sorrells M.E., Genetic studies on seed dormancy in rice, in: *Rice Genetics*, IRRI, Manila, 1986, pp. 369–382.
- [28] Smith R.J. Jr., Control of red rice (*Oryza sativa* L.) in water seeded rice (*Oryza sativa* L.), *Weed Sci.* 29 (1981) 61–62.
- [29] Stoller E.W., Wax L.M., Temperature variations in the surface layers of an agricultural soil, *Weed Res.* 13 (1973) 273–282.
- [30] Tarditi N., Vercesi B., Il riso crodo: un problema sempre più attuale in risicoltura, *Inf. Agrar.* 49 (1993) 91–95.