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Seed Longevity of Rice Cultivars and Strategies for their Conservation in Genebanks

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Changes in seed quality during ripening were studied in sixteen cultivars of rice, representing the three ecogeographic races of *Oryza sativa*, and one cultivar of *O. glaberrima*, grown during one dry season (Nov.–May) 1992–1993 at Los Baños, Philippines. Mass maturity (defined as the end of seed filling period) among the cultivars was attained between 18·5 and 21·6 d after anthesis (DAA). The seed moisture content at mass maturity varied between 24 and 40%. Germination ability of seeds in the early stages of development varied significantly, but as mass maturity approached, germination increased to the maximum and no significant differences were found among cultivars. The seeds were stored hermetically at 35 °C with $15 \pm 0{\cdot}2$% moisture content and the resultant seed survival data were analysed by probit analysis. Potential longevity (quantified by the value of seed lot constant K_i of the seed viability equation) was greatest between 33 and 37 DAA, i.e. about 2 weeks after mass maturity. The stage during development at which seeds achieve maximum potential longevity is described by the term storage maturity. Lowland *japonica* cultivars, large seeded accessions (seed mass $\geqslant 40$ mg) and *O. glaberrima* had shorter storage longevity (σ, standard deviation of the frequency of seed deaths in time = 1·47 weeks) while cultivars with purple pericarp survived longer than other cultivars ($\sigma = 2{\cdot}33$ weeks). The initial germination of the *japonica* cultivars at storage maturity was high (99–100%) and the estimates of maximum potential longevity (K_i) which ranged between 3·3 (Shuang cheng nuo) and 4·4 (Minehikare) were close to those of the *indica* cultivars.

This research suggests that seed production environment between Nov. and May at Los Baños is benign for the temperate *japonica* cultivars. The implications of these results on management of rice genetic resources are discussed.

Key words: *Oryza sativa* L., rice, germplasm conservation, seed production environment, seed development, seed longevity.

INTRODUCTION

Rice is the most important staple food crop of about 60% of the world's population. There are two cultivated species of rice, *Oryza sativa* L. which is native to South and Southeast Asia, and *O. glaberrima* L. which originated in West Africa. The complex array of Asian cultivars are characterized conventionally into three ecogeographic races: *indica* (tropical and subtropical cultivars), *japonica* (temperate cultivars) and *javanica* (cultivars native to Indonesia) (Chang, 1985). Rice like the other arable cereals, produces orthodox seeds which can be dried and stored at low temperatures to prolong viability. Therefore, *ex situ* conservation in a genebank is the principal strategy for rice genetic resources. The rice germplasm collection at the International Rice Genebank (IRG) of the International Rice Research Institute (IRRI) at Los Baños, Philippines (14 °N) now exceeds 80000 accessions and is an important source of genetic diversity for breeders and researchers throughout the world (Jackson and Huggan, 1993). The viability of the stored germplasm accessions is monitored at regular intervals, and accessions which reach low viability (50%) are regenerated. Germplasm regeneration, however, involves the risk of genetic drift due to selection pressures, handling errors, mechanical mixture and outcrossing (Allard, 1970). The tremendous genetic diversity found among rice cultivars compounds these problems. To preserve genetic integrity of the germplasm accessions, frequency of regeneration, therefore should be minimized through maximization of seed storage longevity. The two important factors that affect longevity of an accession during storage – temperature and relative humidity (or seed moisture content) (Roberts, 1972) – are well studied and quantified for rice (Ellis, Hong and Roberts, 1992). But less is known about the preharvest factors – seed production environment and degree of seed maturity – that affect the initial quality and subsequent storage longevity of seeds.

There is considerable evidence to indicate that preharvest environment significantly affects seed quality. Cool sites with low relative humidity (RH) are known to be generally conducive to the production of good quality seeds (Andrews, 1982). The Philippine Islands, however, have a tropical climate which is generally hot with high RH and frequent and prolonged precipitation, therefore unfavourable and detrimental to the production of quality seeds. Harvest delayed beyond optimum maturity can contribute to weathering and rapid deterioration of seeds in such

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environments. Therefore, timely harvest of mature seeds is extremely important to obtain seeds of high quality with maximum potential longevity.

It has been known for a long time that immature seeds lose viability faster than mature seeds under similar storage conditions (Austin, 1972; Justice and Bass, 1978). Harrington (1972) suggested that developing seeds attain maximum viability and vigour at physiological maturity and that they then begin to age, with viability and vigour declining thereafter. Physiological maturity is defined as the stage when seeds reach maximum dry weight during development (Shaw and Loomis, 1950). However, there is now considerable evidence from a wide range of crops including rice (see Ellis, Hong and Jackson, 1993) that developing seeds attain maximum potential longevity some time after the end of the grain filling period, now defined as mass maturity (Ellis and Pieta Filho, 1992). Malabuyoc *et al.* (1966), Sato (1973), Prakobboon (1984) and Yoshida and Hara (1977) studied the changes in dry weight and germinability during ripening in rice, but the results were conflicting and the optimum time to harvest seeds with maximum potential longevity was not defined with certainty.

In rice, Ellis *et al.* (1993) and Ellis and Hong (1994) showed that improvement in longevity subsequent to mass maturity was influenced by the seed production environment and genotype. The potential longevity of the *japonica* cultivars which evolved in temperate environments was significantly less when produced under a warm seed production regime (32/24 °C) than in a cooler regime (28/20 °C). It was suggested that the seed production environment at IRRI in Los Baños may be too harsh for *japonica* cultivars and such accessions might be better regenerated in another cooler environment. However, Ellis *et al.* (1993) and Ellis and Hong's (1994) studies were conducted in the UK under controlled environments and included only one *japonica* and two *indica* cultivars. In view of the serious implication for the management of some 5000 japonica cultivars in the IRRI gene bank, more studies under field conditions at Los Baños, involving a wider range of *japonica* accessions were warranted. Further, the warm temperature regime used in the UK experiment simulated the seed production environment during the wet season at Los Baños. The Los Baños climate is however characterized by a distinct dry season from Nov. to Apr., which is relatively cooler and drier (mean monthly temperature and rainfall vary around 26 °C and 50 mm, respectively) than the wet season, and is therefore likely to be more favourable for seed production. While it is evident from the UK studies that rice seeds produced at Los Baños during the wet season would be inferior for conservation, information on storage longevity of the seeds produced during the dry season is limited. If seeds produced during the dry season did have acceptable quality for conservation, there would be no need to regenerate the *japonica* accessions at another site where conditions should be better suited for this germplasm.

Ellis *et al.* (1993) and Ellis and Hong's (1994) studies also showed that even in the cooler regime, the maximum potential longevity of the seeds of *japonica* cultivars was less than that of the *indica* cultivars. This supported the previous findings of Chang (1991) which showed that *japonica* cultivars, apart from being sensitive to the seed production environment, also possessed intrinsically poorer storage characteristics than the *indica* cultivars. The enormous ecogeographic diversity in the rice germplasm collection at IRRI makes us believe that there may be other cultivars with storage characteristics similar to those of *japonica* cultivars. It is therefore desirable to develop the best strategy for the production of seeds with maximum potential longevity for conservation in the genebank, given the limitations of the tropical environment at Los Baños.

This paper reports the changes in seed quality during ripening and maturation in diverse germplasm grown during the dry season (Nov.–May) 1992–93. The investigations were undertaken to determine whether seeds produced in the dry season at Los Baños provide acceptable seed quality and whether differences in seed storage longevity and development of potential longevity occur among contrasting genotypes. The *javanica* cultivars and upland *indica* rices from Southeast Asia belong to the same isozyme group (VI) as classical *japonica* rices (Glaszmann, 1987), therefore studies were also undertaken to determine whether differences in morphological characteristics and isozyme profile correlate with any differences in inherent longevity of the germplasm cultivars.

MATERIALS AND METHODS

Sixteen cultivars of *O. sativa*, representing the three ecogeographic races, and one cultivar of *O. glaberrima* were used in this investigation. Cultivars adapted to diverse ecological conditions, varying in maturity, seed colour, size, and starch composition (glutinous or non-glutinous) were selected (Table 1). The experiment was conducted during the 1992–1993 dry season (Nov. to May) at the IRRI upland farm, block UV 4. The seeds were sown in a wet seedbed. Four-week-old seedlings were transplanted in $5 \times 1{\cdot}5$ m plots, using a randomized complete block design with two replicate plots, at 0·3 m between rows and 0·25 m between plants in a row, which gave a stand of 16·8 plants m^{-2}. Standard crop production practices were adopted and routine plant protection measures taken. When anthers of the upper third of panicles were dehiscing, flag leaves of individual panicles were marked with the date of flowering. Commencing at day 7 after anthesis, and at weekly intervals until 42 d, about 40–50 panicles for each sampling time were harvested at random from each plot. The seeds were threshed gently by hand and unfilled grains removed. Samples were drawn for dry weight, initial moisture content and germinability determinations, while the remaining seeds were dried for 24 h in a mechanical convection incubator at 30 °C and 20–30 % RH which reduced the moisture content to 10–12 %. The seeds were then stored at 1–2 °C in sealed aluminum foil packets until longevity determination began.

Dry weight observations were based on two 100 seed samples from each plot, dried in a ventilated oven at 80 °C for 3 d. Moisture content determinations were made on two 3–5 g samples from each plot using the high constant temperature oven method, and a two stage drying method was adopted where the moisture content was expected

TABLE 1. *Information on the cultivars of rice used in the experiment*

Cultivar name	IRG accession number	Origin	Subspecies	Ecotype	Isozyme group	Endosperm	Mean seed dry weight (mg)	Days from sowing to anthesis
O. sativa								
Fujisaka 5	244	Japan	*Japonica*	LL	VI	NG	25	56
Tainan 7	10475	Taiwan	*Japonica*	LL	VI	NG	24	79
Minehikare	57031	Korea	*Japonica*	LL	VI	NG	23	53
Shuang cheng nuo	70380	China	*Japonica*	LL	VI	G	24	54
Macunting	3959	Philippines	*Japonica*	UP	VI	NG	10	97
Susono mochi	7689	Japan	*Japonica*	UP	VI	G	26	72
Padi abang go-go	25467	Indonesia	*Javanica*	LL	VI	NG	28	97
Khao khao	11665	Laos	*Javanica*	UP	VI	G	40	86
Khao lo	12904	Laos	*Javanica*	UP	VI	G	45	61
China 1039	24167	China	*Indica*	LL	I	NG	26	60
IR 64	66970	Philippines	*Indica*	LL	I	NG	26	79
Thavalu	15314	Sri Lanka	*Indica*	LL	I	NG	29	74
Anadi	9543	Nepal	*Indica*	LL	I	G	28	68
Palawan	353	Philippines	*Indica*	UP	VI	G	24	84
Tapol	615	Philippines	*Indica*	UP	VI	G	25	90
Perurutong NB A	754	Philippines	*Indica*	UP	VI	G	27	90
O. glaberrima	103326	Senegal	–	–	–	NG	31	53

LL, lowland; UP, upland; NG, nonglutinous; G, glutinous.

to be > 15% (International Seed Testing Association, 1985*a*, *b*).

The germination tests were conducted on 200 seeds (from each plot) as four replicates of 50 seeds each on top of two moist filter papers in 9·0 cm Petri dishes at an alternating temperature regime of 30/20 °C (16/8 h) (Ellis, Hong and Roberts, 1985). The seedlings were evaluated according to the rules of the International Seed Testing Association (International Seed Testing Association, 1985*a*, *b*). Seedlings which produced normal root and shoots were considered to have germinated (normal germination). The first counts of germination were made on day 7, and ungerminated seeds were dehulled to remove any dormancy and tested for another 7 d before the final counts were taken. Seeds which remained ungerminated but became soft at the end of the testing period were considered dead.

The determination of potential longevity of the seed lots began in May 1993, some 2 months after the first sample was harvested, and continued until Sep. 1993. Work was staggered in the same order of flowering in the various cultivars. Within each cultivar, the longevity of seeds harvested at 14, 21, 28, 35 and 42 d after anthesis (DAA) was determined. The seeds dried to 10–12% moisture content and stored at 1–2 °C were withdrawn and held overnight at 25 °C to equilibrate to ambient temperatures. Samples of about 100 g were drawn from each seed lot and the moisture content was adjusted to 15±0·2% by humidification over water in a desiccator at 25 °C for between 8 and 36 h, depending on initial moisture content. The seeds were then stored hermetically at 3–5 °C for 3 d for even distribution of moisture within each seed lot. The moisture content of each seed lot was checked to ensure that the moisture content of the sample was within the expected limits. A sample of 200 seeds was drawn from each seed lot to test the germination. The remaining seeds were then subdivided into 10–15 samples of 200–250 seeds, which were sealed in small laminated aluminum foil packets, leaving minimum air space. They were stored in an incubator at 35±0·2 °C. One sample was removed every week and tested for germination as described above.

RESULTS

The initial flowering time of the 17 cultivars used in this experiment varied between 53 and 97 d from sowing (Table 1). Cultivars Fujisaka 5, Minehikare, Shuang cheng nuo and *O. glaberrima* were the earliest to flower, while Macunting, Padi abang go-go, Tapol and Perurutong NB A were among the last to flower. Within each panicle, anthesis was completed within 3–5 d. Length of flowering varied between 12 and 26 d among cultivars; it was shortest in IR 64 and longest in Khao lo and *O. glaberrima* (data not shown).

The data on dry weights, moisture content, and germinability of the developing seeds were subjected to repeated measures analysis of variance (SAS Institute Inc., 1985). The effects of harvest time and cultivar were highly significant ($P < 0·001$), but the interactions between time of harvest and cultivar were not ($P > 0·05$), this suggested that the trend of changes in dry weight, moisture content, and germinability was similar across cultivars.

The dry weight of most cultivars increased rapidly until it reached maximum by 21 DAA, with little subsequent change during the following 28–42 DAA (Figs 1 and 2). The rate of increase in dry weight between 7 and 21 DAA significantly differed among cultivars ($P < 0·01$) and closely correlated with grain size ($r^2 = 0·94$). Mass maturity or the end of grain filling period was estimated for each cultivar by fitting a positive relation to the dry weight observations between 7 and 21 d and a horizontal line thereafter, and then assessing the day on which the two fitted lines intercept

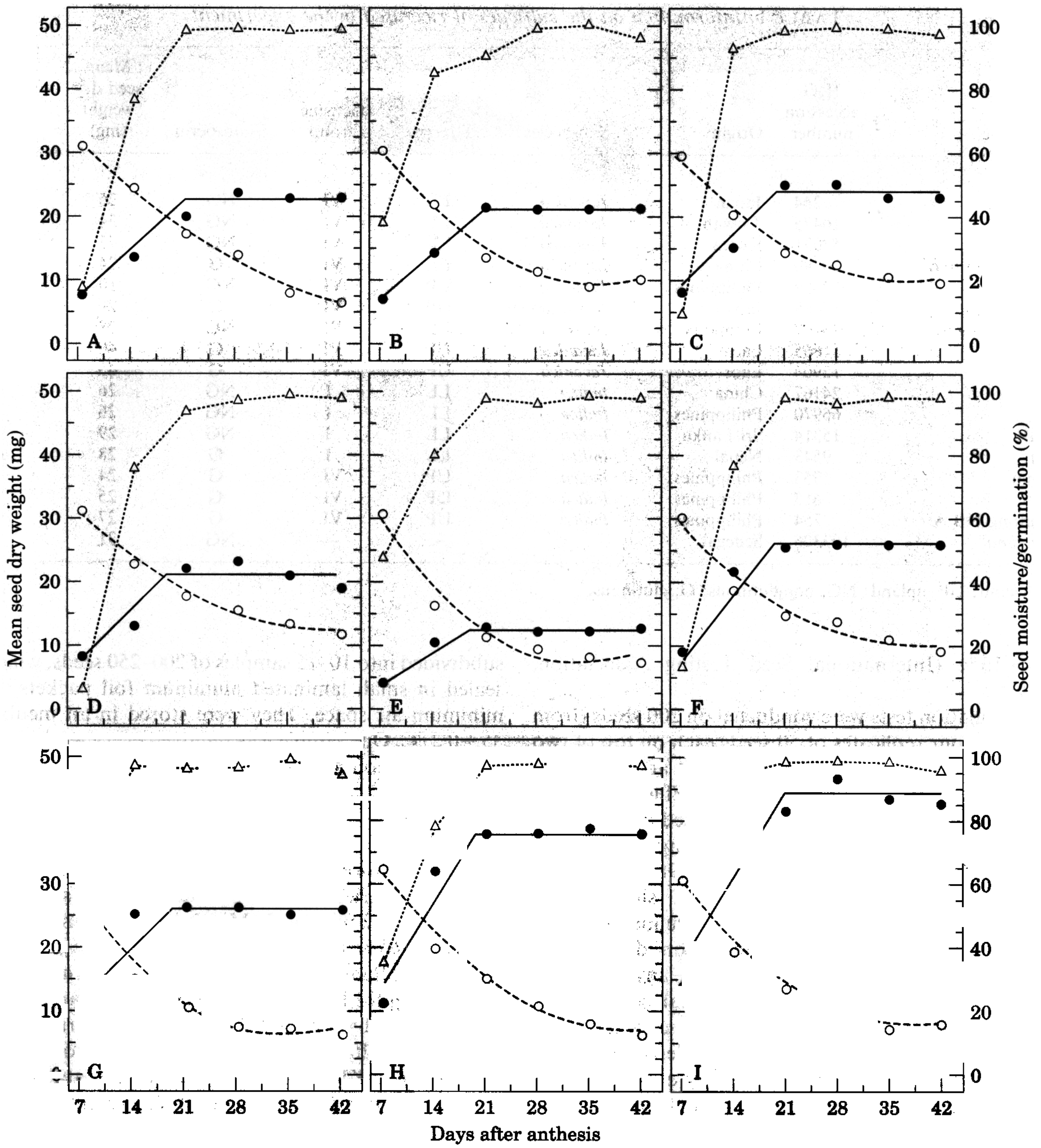

FIG. 1. Mean dry weight (●), moisture content (○) and initial germination (△) during seed development and maturation in six *japonica* (A–F) and three *javanica* (G–I) cultivars of rice. The end of the grain filling period (mass maturity) is denoted by the intersection of the two lines for the mean dry weight with time. A, Fujisaka 5. B, Tainan 7. C, Minehikare. D, Shuang cheng nuo. E, Macunting. F, Susono mochi. G, Padi Abang go-go. H, Khao khao. I, Khao lo.

each other. The estimates of mass maturity varied between 18·5 and 21·6 DAA with a mean of 19·6±0·32 (Figs 1 and 2). Differences in time to achieve mass maturity were not significant among cultivars ($P > 0{\cdot}05$). The seed dry weight at mass maturity ranged between 12·2 mg (Macunting) and 44·6 mg (Khao lo) among the cultivars.

The moisture content of the developing seeds ranged between 64 (Khao lo) and 51 % (Padi abang go-go) with a mean of 60 % on day 7 after anthesis, but it declined gradually as the seeds advanced in maturity. Moisture content ranged between 12 (Palawan) and 23 % (Shuang cheng nuo) with a mean of 15 % at 42 DAA (Figs 1 and 2). Changes in moisture content with time were described by fitting second degree polynomials to the data and the model accounted for a percentage variance between 89·6 (Anadi) and 99·2 (Khao lo) among different cultivars (data not shown). The moisture content at mass maturity estimated from the coefficients of regression ranged between 23·9 (Thavalu) and 39·9 % (Shuang cheng nuo) with a mean of 29·5±0·95 %. Glutinous cultivars (endosperm rich in amylo-

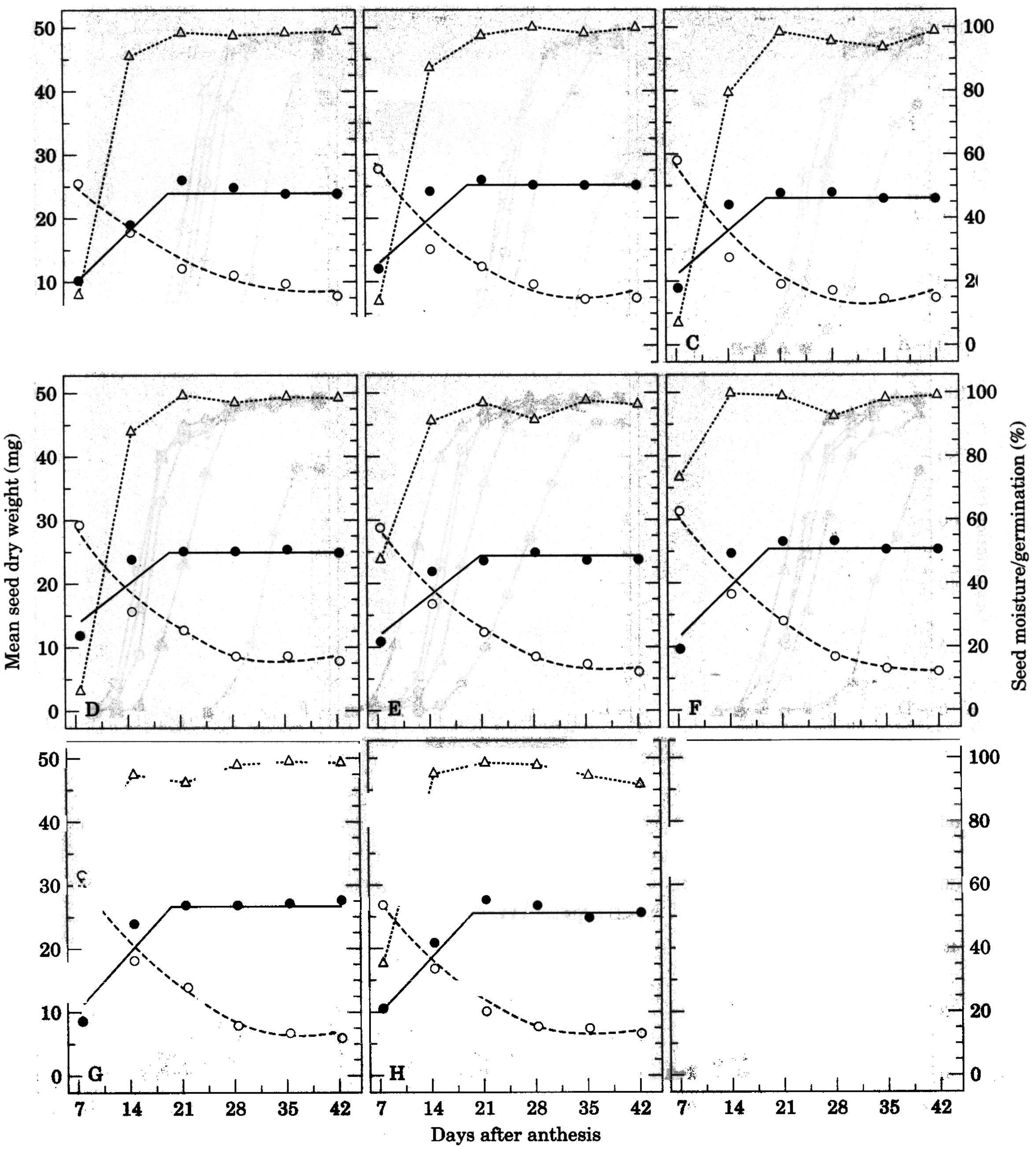

FIG. 2. Mean dry weight (●), moisture content (○) and initial germination (△) during seed development and maturation in seven *indica* cultivars of *O. sativa* (A–G) and one cultivar of *O. glaberrima* (H). The end of the grain filling period (mass maturity) is denoted by the intersection of the two lines for the mean dry weight with time. A, China 1039. B, IR 64. C, Thavalu. D, Anadi. E, Palawan. F, Tapol. G, Perurutong NB A. H, *O. glaberrima* (103326).

pectin), generally had a higher moisture content on any given date of harvest (Figs 1 and 2).

Germinability of the seeds varied significantly among cultivars during the early stages of maturation. At 7 DAA, germinability ranged from 1 (Shuang cheng nuo, Fig. 1D) to 76% (Perurutong NB A, Fig. 2G), with a mean of 31%. At 14 DAA, the range was between 77 (Fujisaka 5, Fig. 1A) and 100% (Tapol, Fig. 2F) with a mean of 87% (Figs 1 and 2). Nevertheless, it increased to the maximum as the seeds approached mass maturity and germinability of near mature and mature seeds did not differ significantly among cultivars. The mean maximum germination of 97% that occurred at 21 DAA closely coincided with the accumulation of mean maximum dry weight among cultivars. Considerable dormancy was encountered in the early harvests for most cultivars (data not presented), which however reduced naturally with seed development and maturation.

Seed longevity

Sufficient seeds for longevity studies were not obtained in one plot for all harvest dates in cultivars Fujisaka 5, Tainan

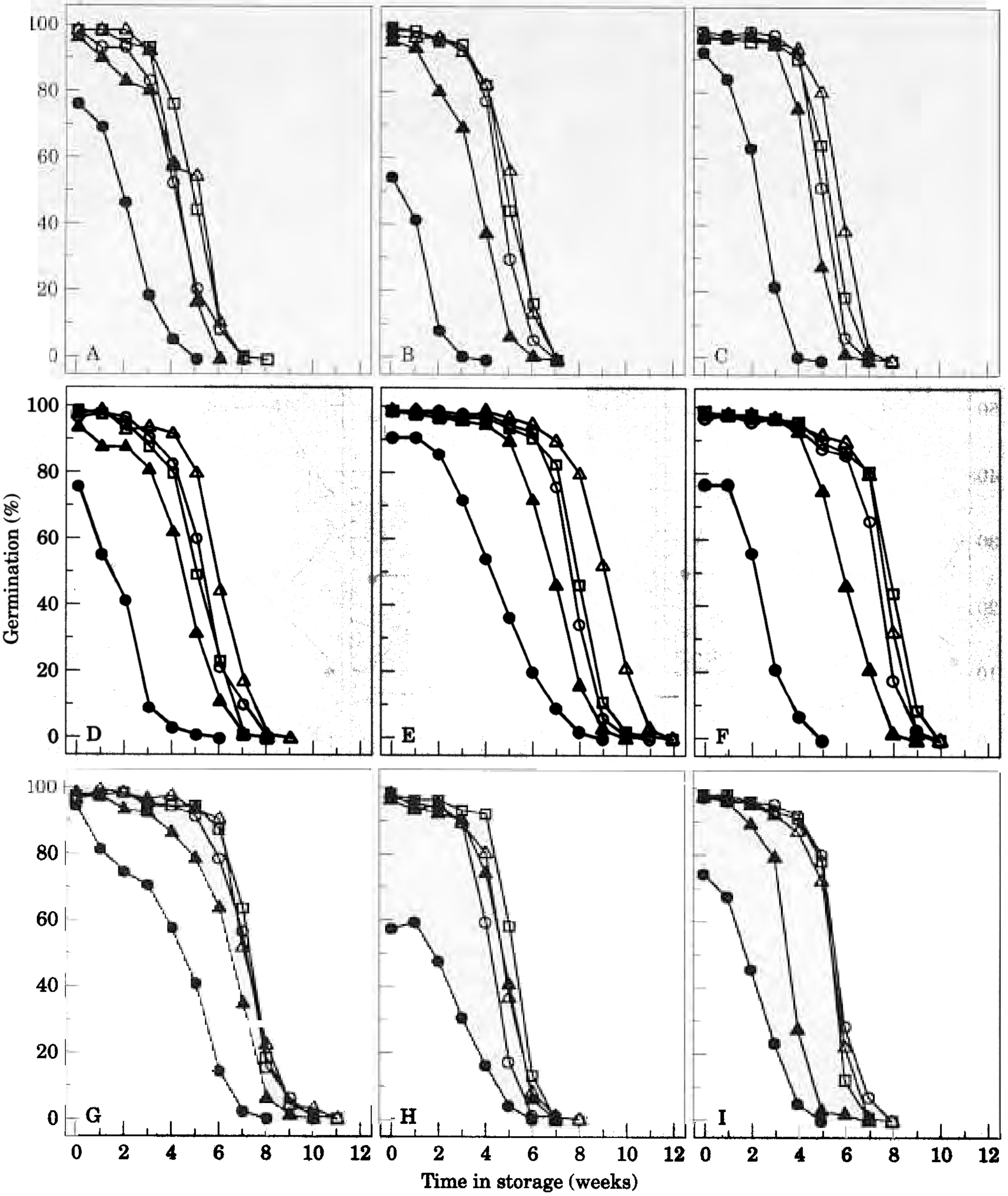

FIG. 3. Seed survival curves (% normal germination plotted against time in storage) in six *japonica* (A–F) and three *javanica* (G–I) cultivars of rice. The seeds were harvested at 14 (●), 21 (▲), 28 (○), 35 (□) and 42 (△) DAA and stored hermetically in laminated aluminum foil packets at 35 °C with 15±0·2% moisture content. A, Fujisaka 5. B, Tainan 7. C, Minehikare. D, Shuang cheng nuo. E, Macunting. F, Susono mochi. G, Padi Abang go-go. H, Khao khao. I, Khao lo.

7, Shuang cheng nuo, and *O. glaberrima*, and for the 14 d harvest in cultivars Susono mochi and Thavalu. Complete survival curves were obtained for all the remaining 148 seed lots. During storage, all seed lots lost viability gradually, but differences in rate of loss of viability were apparent among cultivars and between different dates of harvest within each cultivar. The seed survival curves (normal germination plotted against time in storage) were sigmoid in shape implying normal distribution of seed deaths (Figs 3 and 4). Potential longevity of the seed lot was quantified by estimating the value of seed lot constant (K_i), which is provided by the intercept of the seed survival curve determined by probit analysis according to the equation,

$$v = K_i - p/\sigma, \qquad (1)$$

in which v is the probit percentage germination after p days of storage, and σ is the standard deviation of the frequency distribution of seed deaths in time, while K_i is the seed lot constant (Ellis and Roberts, 1980). The genotype and pre-storage environment, including the degree of seed maturity

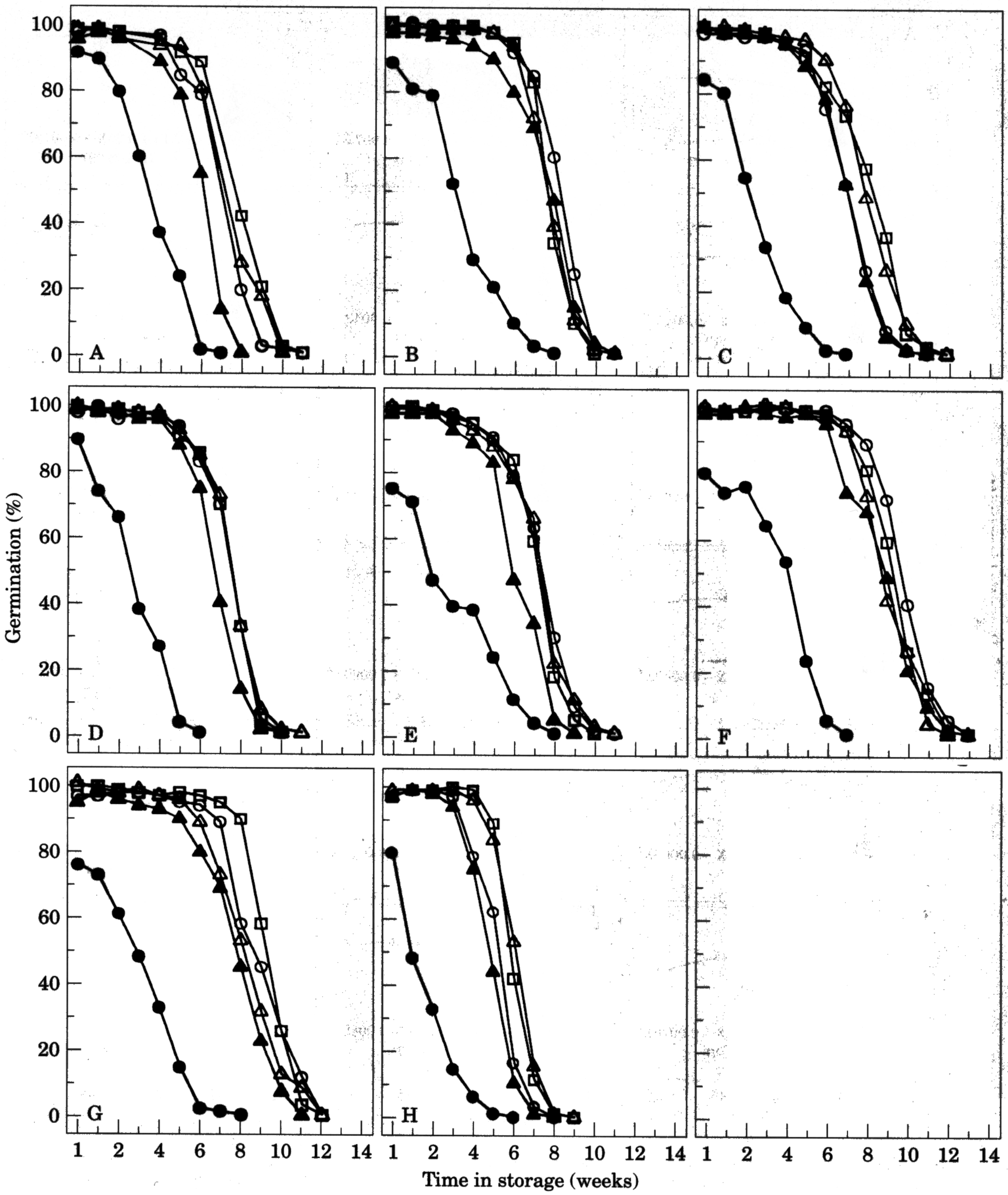

FIG. 4. Seed survival curves (% normal germination plotted against time in storage) in seven *indica* cultivars of *O. sativa* (A–G) and one cultivar of *O. glaberrima* (H). The seeds were harvested at 14 (●), 21 (▲), 28 (○), 35 (□) and 42 (△) DAA and stored hermetically in laminated aluminum foil packets at 35 °C with 15 ± 0·2 % moisture content. A, China 1039. B, IR 64. C, Thavalu. D, Anadi. E, Palawan. F, Tapol. G, Perurutong NB A. H, *O. glaberrima* (103326).

and environmental conditions around the time of harvest affect storage potential, therefore the value of the constant K_i. These factors do not influence the slope ($1/\sigma$) of the survival curves, which is markedly affected by the storage conditions.

Within each cultivar, there were no significant differences between the two plots (except in Palawan and Macunting, where the differences for day 14 harvest were significant, $P < 0{\cdot}01$). Further, the slopes ($1/\sigma$) of the survival curves of seed lots harvested at different times within each cultivar were found to be similar ($P > 0{\cdot}05$). Estimates of the seed lot constant K_i, differed significantly among harvest dates within each cultivar ($P < 0{\cdot}001$). In most cultivars, potential longevity increased between 14 and 35 DAA, but the rate of increase in K_i declined throughout this period such that the improvement in K_i was negligible for the later harvests. Changes in potential longevity during seed development were described closely by fitting second degree polynomials to the values of K_i from each plot and the time for maximum potential longevity for each cultivar was estimated from the

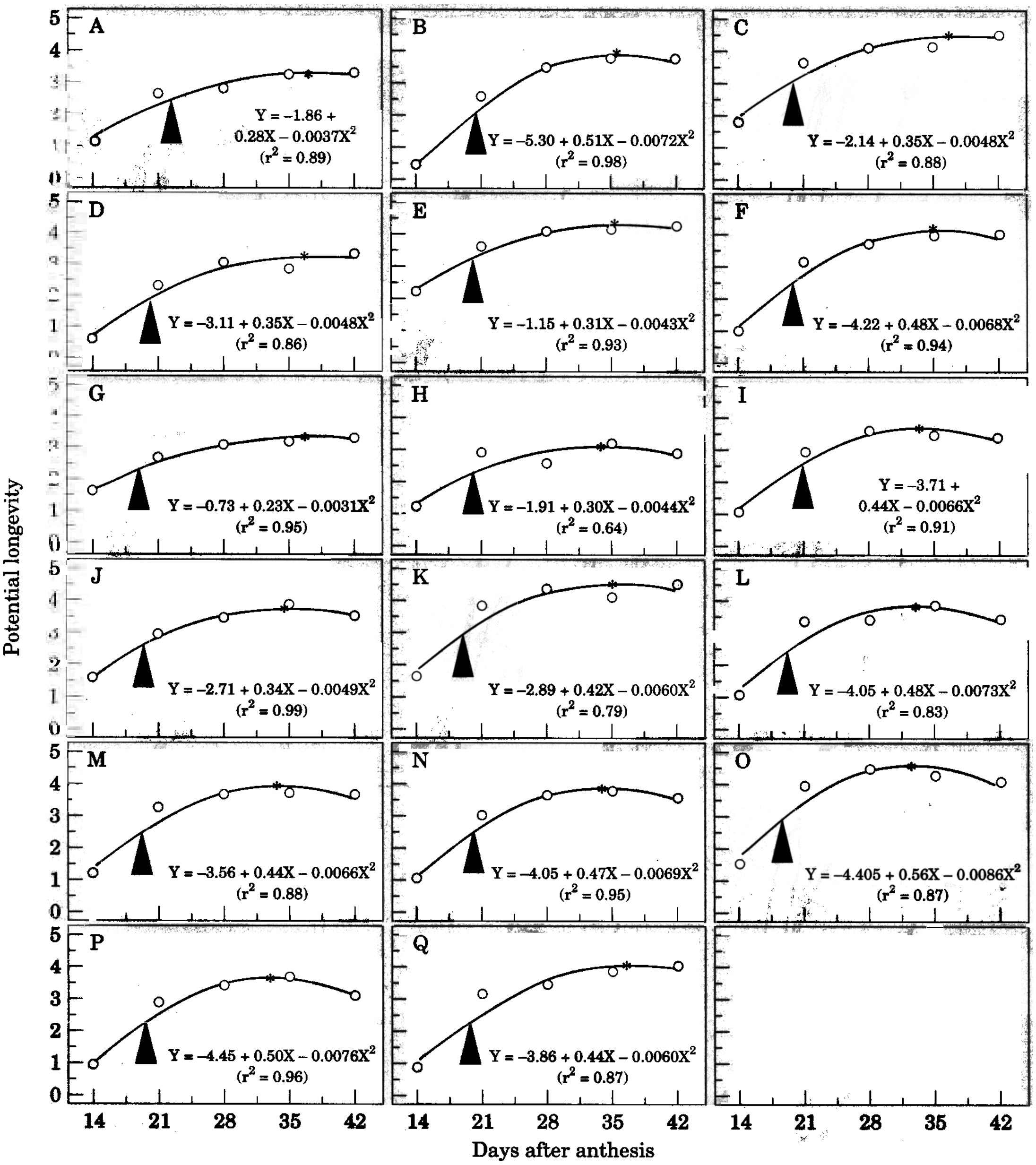

FIG. 5. Changes in potential longevity of seeds (estimate of seed lot constant K_i of seed viability eqn., $v = K_i - p/\sigma$) harvested at different stages of maturity in six *japonica* (A–F), three *javanica* (G–I) and seven *indica* (J–P) cultivars of *O. sativa* and one cultivar of *O. glaberrima* (Q). The seeds were stored in laminated aluminum foil packets at 35 °C with 15±0·2 % moisture content. The solid lines represent the fitted equation, the arrows indicate mass maturity and *, maximum potential longevity. A, Fujisaka 5. B, Tainan 7. C, Minehikare. D, Shuang cheng nuo. E, Macunting. F, Susono mochi. G, Padi Abang go-go. H, Khao khao. I, Khao lo. J, China 1039. K, IR 64. L, Thavalu. M, Anadi. N, Palawan. O, Tapol. P, Perurutong NB A. Q, *O. glaberrima* (103326).

coefficients of regression (Fig. 5). Maximum potential longevity was obtained between 32 and 37 DAA at a mean time of 35·3±0·36 DAA, i.e. about 16 d after mean mass maturity. Analysis of variance revealed no significant differences ($P > 0{\cdot}05$) among cultivars in the time to reach maximum potential longevity. The values of maximum K_i attained by the cultivars ranged between 3·1 (Khao khao) and 4·7 (Tapol) with a mean of 3·8±0·11 (Figs 3 and 4).

A comparison of the estimates of standard deviation of the frequency distribution of seed deaths among cultivars indicated highly significant differences ($P < 0{\cdot}001$). The 17 cultivars investigated here were categorized into three groups. The survival curves of seven out of the 17 cultivars—lowland *japonica* cultivars (Fujisaka 5, Tainan 7, Minehikare and Shuang cheng Nuo), large seeded *javanica* cultivars (Khao khao, Khao lo), and *O. glaberrima*—were steeper (Figs 3 and 4) and had a common slope (−0·6796±0·0049) with the estimate of σ (1·47 weeks) less than that of others. Two cultivars with purple pericarp, Tapol and Perurutong NB A, survived longer (Fig. 4) and had a common slope (−0·4281±0·0041) with the estimate of σ (2·33 weeks) greater than that of all other cultivars. The seed survival curves of the other eight cultivars, which included lowland and upland *indica* (China 1039, IR 64, Thavalu, Anadi and Palawan), upland *japonica* (Macunting, Susono mochi) and the lowland *javanica* (Padi abang go-go) had a common slope ($-0{\cdot}5042 \pm 0{\cdot}0025$) with σ (1·98 weeks), intermediate between the above two extremes.

DISCUSSION

To maximize seed longevity, it is important to harvest seeds at optimal maturity. The results of the study showed that rice seeds produced during the dry season at Los Baños attain maximum potential longevity by 35 DAA. We suggest the term 'storage maturity' to denote the stage during development that seeds achieve their maximum potential longevity. Unlike other cereals (barley, wheat and pearl millet), where seed quality has been shown to decline subsequent to achievement of maximum longevity (Kameswara Rao *et al.*, 1991; Ellis and Pieta Filho, 1992), rice showed no evidence of any major change in potential longevity (at least until 42 DAA) as also reported by Ellis *et al.* (1993). However, considering the potential risks (storms, diseases etc.) associated with tropical environments, it would appear sensible to harvest seeds at the earliest appropriate opportunity, i.e. about 5 weeks after anthesis. It is interesting to note that the optimum time to harvest for obtaining maximal yield and highest germination were also reported to be between 28–34 d in the dry season (Nangju and De Datta, 1970).

The results presented for the 17 cultivars are in general agreement with other studies on rice (Ellis *et al.*, 1993; Ellis and Hong, 1994) and other cereals (Kameswara Rao *et al.*, 1991; Pieta Filho and Ellis 1991; Ellis and Pieta Filho, 1992) which showed that maximum potential longevity is not attained until some time after mass maturity. They contradicted the hypothesis that vigour and viability are maximum at physiological maturity and decline thereafter as seeds begin to age (Harrington, 1972). In the present study, while mass maturity was attained at a mean time of 19 DAA, maximum potential longevity was achieved about 16 d later, i.e. at 35 DAA, as the mean moisture content decreased from 29·5% at mass maturity to 15·6 ± 0·8%.

Ellis *et al.* (1993) reported that in the warmer regime the maximum initial germination of seeds of the *japonica* cultivar never exceeded 90% and the values of K_i were significantly less than those attained in the cooler seed production regime or those attained in the warmer regime by the *indica* cultivars. In the present study initial germination of seeds of *japonica* cultivars at mass maturity was close to 100% (Figs 1 and 2) and the values of maximum potential longevity were similar to those attained by other *indica* cultivars. The mean temperature (25–26 °C) recorded during seed ripening of *japonica* cultivars is close to the average temperatures of the cooler regime in the UK experiment (24 °C), therefore it is apparent that the environment during the early part of the dry season (Dec.–Feb.) at the IRRI farm is not that harsh for seed production in *japonica* cultivars. The average temperatures during the rainy season (Jun.-Oct.) at IRRI are expected to be similar to the mean temperature of the warmer seed production regime (28 °C) in the UK experiment, and in the absence of any evidence to the contrary, they are unlikely to be favourable for production of good quality seeds in *japonica* cultivars. The prolonged and frequent precipitation and adverse weather conditions due to tropical depressions or even typhoons can seriously affect the initial quality of the seeds, more so in *japonica* cultivars, which are non-dormant. Therefore regeneration of germplasm accessions in the rainy (wet) season for conservation in a long-term genebank should be avoided.

The present study confirmed the earlier findings of Chang (1991) and Ellis *et al.* (1992) on varietal differences in seed longevity of rice. It should be noted that upland *japonica* cultivars differed from lowland *japonica* cultivars, although both belong to the same isozyme group VI (Table 1), indicating no precise agreement between isozyme classification and differences in survival among cultivars. On the other hand, the storage longevity of the different ecotypes among *indica* cultivars was generally similar. In addition to the lowland *japonica*, large-seeded cultivars and *O. glaberrima* also had poorer storage characteristics. Interestingly, cultivars with purple pericarp had greater storage longevity than others studied here. Although the reasons for this are not clear, it could be related to the level of phenolic content and the associated antioxidative defence system (see Ramarathnam *et al.*, 1986). Biochemical investigation of the hull and pericarp extracts of these cultivars is worth pursuing. Although reports have indicated that glutinous (high in amylopectin) rice cultivars lose viability faster than nonglutinous (high in amylose) cultivars (Juliano, Perez and Chang, 1990), the present study failed to reveal differences in seed longevity between them. In this study, the moisture content of the seeds of all cultivars during storage was adjusted to 15 ± 0·2%. This is in contrast with other experiments where seeds were stored under ambient conditions at 60–80% RH. The hygroscopic equilibria of rough rice correlates negatively with amylose content above 75% RH (Juliano, 1964). Consequently, the moisture content of glutinous rices is expected to be higher than non-glutinous rices which could have led to their faster deterioration.

The present study established no causal relationship between dormancy and seed longevity as also found by Roberts (1963) and Juliano *et al.* (1990). For example, seeds in early stages of maturation were observed to be more dormant (data not shown), yet their potential longevity was much less than those of more mature or mature seeds. Similarly, *O. glaberrima* used in this experiment, had greater dormancy than other cultivars at all maturities, but lost viability faster than some of the nondormant cultivars such as China 1039 and IR 64.

Finally, the results presented here indicated that the seed production environment at IRRI during the dry season is more benign than originally anticipated for seed quality, especially of the *japonica* accessions, which were known to be sensitive to the tropical environment. Seeds with reasonably good quality and potential longevity can be obtained by harvesting at about 35 DAA. Although panicles were tagged in this investigation to minimize variation in chronological age of seeds within a sample, harvest maturity can be estimated from the date when the maximum number of panicles are exerted in the accession. In view of the significant cultivar differences observed in seed storage longevity, it is advisable during storage to monitor more frequently the viability of accessions with intrinsically poor storage characteristics e.g., lowland *japonica*, large-seeded cultivars (with seed mass ± 40 mg) and *O. glaberrima*. This ensures timely regeneration before viability reaches an unacceptably low level. Although the present study encompassed the broad spectrum of variation generally found in rice, the enormous genetic diversity in rice germplasm collections suggests that further investigations on the storage characteristics of cultivars from more diverse ecological habitats should be carried out.

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