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Effects of Seed Rhizome Size on Growth and Yield of Turmeric (*Curcuma longa* L.)

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Abstract : Turmeric (*Curcuma longa* L) plant species produces different sizes of daughter rhizomes (R) and mother rhizomes (MR), which are the only propagules (seed) for its cultivation. Here, we evaluated the effects of seed rhizome size on growth and yield of turmeric. Daughter rhizomes of 5-50 g (R-5 g~R-50 g) and mother rhizomes of 48-52 g (MR) were tested. The heavier the R up to 40 g, the better the plant growth, and the plants from the R-30 g, R-40 g, R-50 g and MR grew similarly well. The seed rhizomes with a greater diameter developed vigorous seedlings. The plants grown from R-30 g, R-40 g and R-50 g had a similar plant height, tiller number and leaf number, which were significantly higher than those from lighter R. The plants from R-30 g, R-40 g and R-50 g had a significantly larger shoot biomass and higher yield than those from smaller R in both the greenhouse and field experiments. R-50 g was easily broken at the time of planting, and had secondary and tertiary daughter rhizomes, which developed thinner plants and resulted in a lower yield. The shoot biomass and yield were highest in the plants grown directly from MR, and lower in the plants grown from daughter rhizomes attached to MR. This study indicates that the turmeric seed rhizome should be 30-40 g with a larger diameter, and seed mother rhizome should be free from daughter rhizomes.

Key words : Daughter rhizome, Early growth stage, Mother rhizome, Rhizome development, Shoot elongation pattern.

Use of turmeric (*Curcuma longa* L.), a rhizomatous perennial plant of Zingiberaceae family, can be traced back nearly 4000 years, to the Vedic culture in India, when turmeric was the principal spice and also had religious significance. Turmeric is listed in an Assyrian herbal dating about 600 BC. Turmeric is widely used as a spice, cosmetic and medicine in Bangladesh, India, Myanmar, Pakistan, Sri Lanka and Thailand (Hermann and Martin 1991; Ishimine et al., 2003). Curcuminoids in turmeric have anti-inflammatory, antimutagen, anticancer, antibacterial, anti-oxidant, antifungal, antiparasitic and detoxifying properties (Hermann and Martine, 1991; Nakamura et al., 1998; Osawa et al., 1995; Sugiyama et al., 1996; Uechi et al., 2000). Curcumin and volatile oils of turmeric prevent tumor formation, improve liver and kidney functions, and could be used against biliary disorders, diabetic and hepatic disorders (Hermann and Martin, 1991). Many people in the world are taking turmeric in different forms for promoting health.

Evaluating the effects of seed size on growth and development of plants is very important for increasing yield in the plant species producing different sizes of seed (Singh and Singh, 2003; Stougaard and Xue, 2004; Xue and Stougaard, 2002). An optimum seed root in size of a specific root crop may develop healthy seedling and vegetative parts, which subsequently receive higher solar energy and maximize yield. In general, ginger, potato, taro and turmeric (*Curcuma* sp.) plants produce different sizes of propagules. The turmeric plant propagates by mother rhizome (shoot base) and daughter rhizome. The daughter rhizomes of the species are considered to be different in size, because primary daughter rhizomes developed from the shoot base have secondary and tertiary daughter rhizomes, which are different in size due to the differences in developing time. In addition, all the primary daughter rhizomes are not developed at a time from a shoot base. Therefore, it is necessary to determine the optimum size of seed rhizomes for turmeric cultivation.

Many studies on medicinal value of turmeric have been published but very few on its cultivation (Hermann and Martin, 1991; Ishimine et al., 2003). Turmeric is commercially cultivated in the south-western part of Japan due to the subtropical climate, but its production is limited because of the local farmers lack proper cultivation technology (Akamine et al. 1994, 1995; Aoi et al., 1988; Aoi, 1992; Ishimine et al., 2003). Typhoons hit Okinawa several times a year, and cause severe damage to plants. It was hypothesized that the plants from the optimum seeds in size could

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establish better, and survive well in typhoon disaster by developing roots and increasing shoot diameter. We have determined optimum planting time, depth, pattern and space of planting for turmeric cultivation (Ishimine et al., 2003, 2004). Present study has been undertaken to evaluate the effect of seed rhizome size on growth and yield of turmeric.

Materials and Methods

1. Trial site and soil characteristics

Two greenhouse and two field experiments were conducted in 1999-2000 and 2003 at the Subtropical Field Science Center of the University of the Ryukyus, Okinawa (24-28° N. Mean yearly ambient temperature, rainfall and percent humidity during 1999-2003 were 23.3±0.2 °C, 2198±436 mm and 72.2±2.1%, respectively. Data were collected from the Meteorology Branch Office, Naha), Japan. The experiments were conducted on dark red soil (Shimajiri Maji, Chromic Luvisols) containing 0.8% organic matter, 0.89% C, 0.11% N, 134 mg P per 100 g soil, and pH 6.08. Percent (w/w) clay, silt and sand were 66.3, 29.3 and 4.4%, respectively, and bulk density of soil (g cm^{-3}) was 0.85. Exchangeable K, Ca, Mg and Na were 0.17, 10.8, 1.35 and 0.31 meq (milligram equivalent) per 100 g soil, respectively.

2. Greenhouse experiment 1999-2000

This experiment was conducted from April 20, 1999 to January 28, 2000, using wagner pots (size 0.05 m^2). Each pot was filled with 10 kg of air-dried soil. The seed rhizomes used in this experiment as the treatments were daughter rhizome (R) of 5 g (R-5 g), R-10 g, R-15 g, R-20 g and mother rhizome of 48-52 g (MR). One seed rhizome per pot was planted at the depth of 6 cm. Each treatment had 10 replications (10 pots). Chemical fertilizer (N : P_2O_5 : K_2O = 1 : 1 : 2) was applied at 4 g pot^{-1} 3 times at a 60-day interval from the 2nd to 3rd leaf stage. Water was supplied adequately every day for maintaining optimum soil moisture level for proper seedling emergence and plant growth.

3. Greenhouse experiment 2003

This experiment was conducted from 22 April to 15 December 2003. Each wagner pot (size 0.05 m^2) was filled with 10 kg of air-dried soil and 1 kg of farmyard manure (cow dung). The seed rhizomes used were R-20 g, R-30 g, R-4 g, R-50 g and MR. Each treatment had 6 replications. Soil, plantation procedure, chemical fertilizer, and water used in this experiment were the same as those in 1999-2000. We did not use R-5 g, R-10 g, and R-15 g because they showed a very low yield in preceding experiment (1999-2000).

4. Field experiment 1999-2000

The experiment was conducted from April 20, 1999 to February 5, 2000. The field was plowed to a depth

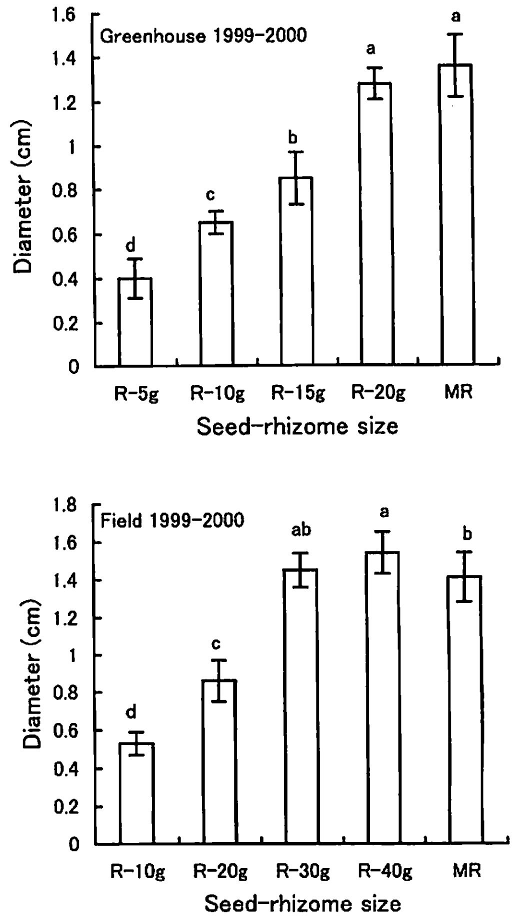

Fig. 1. Effects of seed rhizome size on pseudostem diameter of turmeric seedling 10 cm in height. R: daughter rhizome; MR: mother rhizome. Data are means±SD. Data were from 10 seedlings for each treatment in both the greenhouse and field experiments in 1999-2000. Bars with the same letter are not significantly different at 5% level, as determined by LSD test.

of 35 cm, and 6-m long ridges spaced 150 cm apart were made by furrowing. The seed rhizomes used treatments were R-10 g, R-20 g, R-30 g, R-40 g and MR. Each treatment had three replications (three ridges), and 42 seed rhizomes were planted manually at the 10 cm depth with 30 cm space in two rows on each ridge. Chemical fertilizer (N : P_2O_5 : K_2O = 1 : 1 : 2) was applied at 300 kg ha^{-1} 3 times at a 60-day interval from the 2nd to 3rd leaf stage. Overhead irrigation was given immediately after turmeric planting and fertilizer application. Weeding was performed by hand at 45, 85 and 130 days after planting (DAP).

5. Field experiment 2003

This experiment was conducted from April 23 to December 15, 2003 in the same field. The field was plowed to 35 cm depth, and 4-m long ridges spaced 150 cm apart were made by furrowing. The seed rhizomes tested were R-20 g, R-30 g, R-40 g, R-50 g

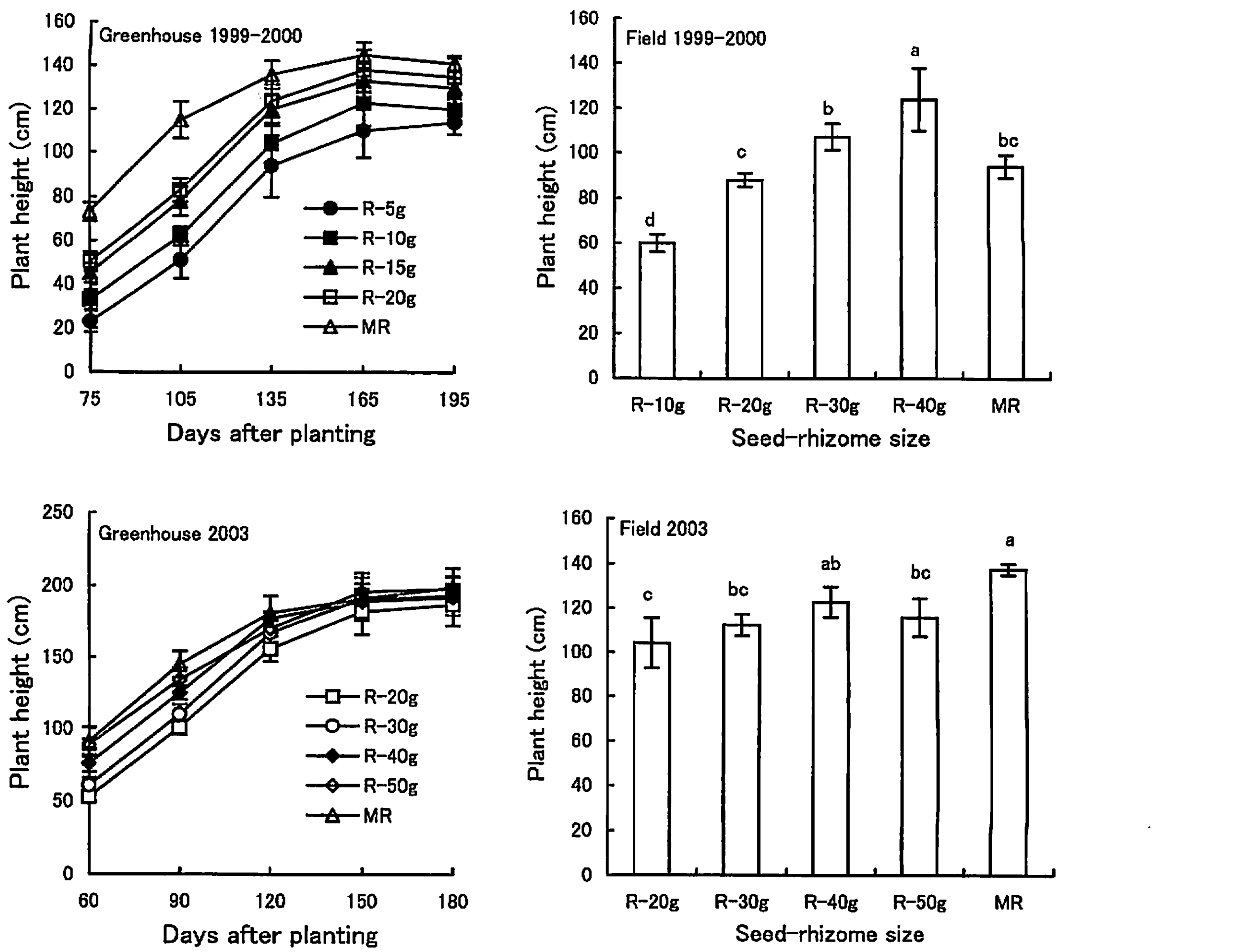

Fig. 2. Effects of seed rhizome size on turmeric plant height. R: daughter rhizome; MR: mother rhizome. Data are means±SD. Data were from 5 and 6 plants for each treatment in the greenhouse experiment 1999-2000 and greenhouse experiment 2003, respectively. In both field experiments, data were from 6 plants for each replication at 105 days after planting and means were calculated, then means for the treatments were calculated from three replications. Bars with the same letter are not significantly different at 5% level, as determined by LSD test.

and MR. Each treatment had three replications, and each replication had 3 ridges where 84 seeds were planted. Turmeric plantation procedure, fertilizer and water used in this experiment were similar to the field experiment in 1999-2000. Hand hoeing was done at 60, 120 and 160 DAP.

6. Procedures of data collection and statistical analysis

Seedlings were counted at 10-day intervals until all seedlings emerged. Seedling (pseudostem) diameter was measured at the soil surface when seedlings grew at least 10 cm in height. Length and width of the first and second leaf blade of the seedlings were measured for the second greenhouse experiment. Shoot elongation was recorded at 15-day intervals until the shoots length reached a plateau in greenhouse experiments. Number of tillers (shoots) and leaves was counted at 135 and 120 DAP in the greenhouse experiment in 1999-2000 and 2003, respectively. In the greenhouse experiment in 1999-2000, five plants from each treatment were harvested at 165 DAP, and leaf area and dry weight of leaf, shoot and rhizome (yield) were measured. The remaining five plants were harvested at maturity when all shoots withered completely (280 DAP). For the greenhouse experiment in 2003, all plants were harvested at maturity (240 DAP). Dry weight of shoots and rhizomes were measured for both the greenhouse experiments. In the field experiment in 1999-2000, plant height, number of tillers and leaves, leaf area, and dry weight of shoots and rhizomes were measured for six plants from each replication at 105 DAP. Turmeric shoot damage caused by typhoons was visually evaluated on the basis of shoot broken and uprooting; and damage recovery level was visually evaluated on the basis of new leaf and tiller formation, and shoot survival. Canopy structure was also visually evaluated. At maturity, the dry weight of shoots and

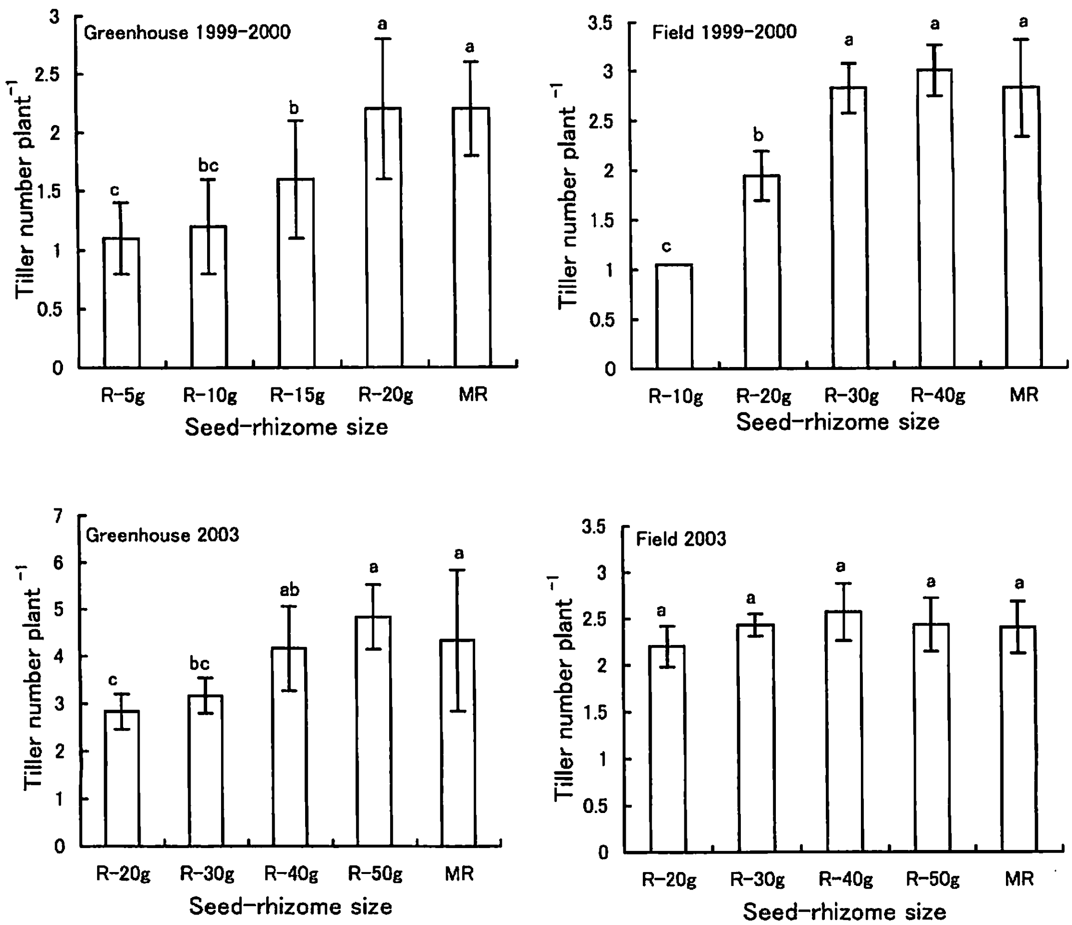

Fig. 3. Effects of seed rhizome size on tiller formation of turmeric plants. R: daughter rhizome; MR: mother rhizome. Data are means±SD. Data were from 5 and 6 plants for each treatment in the green experiment 1999-2000 and greenhouse experiment 2003, respectively. For both the field experiments, data were from 6 plants for each replication and means were calculated, then means for the treatments were calculated from three replications. Bars with the same letter are not significantly different at 5% level, as determined by LSD test.

rhizomes was measured for both field experiments. The number of primary daughter rhizomes was counted for 10 plants from each treatment in the field experiment in 1999-2000. Weed biomass was measured at weeding time. Plant parts were oven-dried at 80 °C for 48 hr and weighed. Means and standard deviations (SD) of samplings were determined using analysis of variance (ANOVA). Fisher's Protected LSD test at the 5% level of significance was used to compare treatment means.

Results

1. Seedling emergence, seedling stem diameter and plant height

Seedlings emerged at almost the same time irrespective of the size of seed rhizomes. Seedling stems were thinner when emerged from R-5 g~R-20 g in both the greenhouse and field experiments, and seedlings from R-30 g, R-40 g and MR had a similar stem diameter in the field experiment (Fig. 1). Plant height increased rapidly until 135 days after planting (DAP), and it increased slowly thereafter up to 160 and 180 DAP in 1999-2000 and 2003, respectively, and reached a constant height in all treatments in both greenhouse experiments (Fig. 2). The larger the seed rhizome, the higher the plant height throughout the observation periods in both greenhouse experiments, but in a greenhouse experiment of 2003, the heights of plants from all seed rhizomes were similar at 180 DAP. The height of plants in field experiments also increased with increasing size of seed rhizome. The height of the plants from MR was significantly lower than those from R-40 g in the first experiment (Fig. 2), whereas it was the highest in the second experiment. However, the plants from R-30 g, R-40 g and R-50 g in the second experiment reached the same level, and these plants were significantly taller than the plants grown from smaller seed rhizomes.

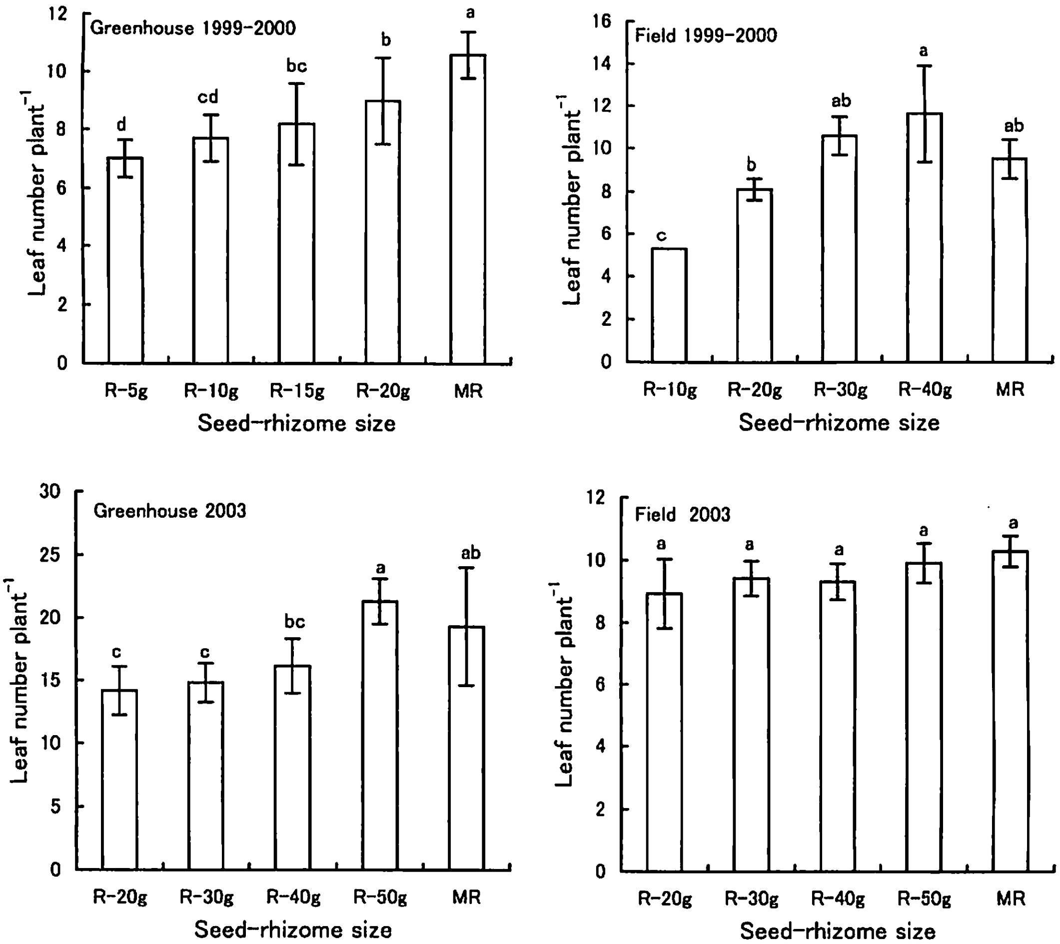

Fig. 4. Effects of seed rhizome size on leaf formation of turmeric plants. R: daughter rhizome; MR: mother rhizome. Data are means±SD. Data were from 5 and 6 plants for each treatment in the greenhouse experiment 1999-2000 and greenhouse experiment 2003, respectively. For both the field experiments, data were from 6 plants for each replication and means were calculated, then means for the treatments were calculated from three replications. Bars with the same letter are not significantly different at 5% level, as determined by LSD test.

2. Number of turmeric tillers

In the greenhouse experiments, the number of tillers increased with the increase in seed size (Fig. 3). In 1999-2000, it was significantly lower in the plants from R-5 g~R-15 g than in those from R-20 g and MR but in 2003, the plants from R-40 g, R-50 g and MR produced a similar number of tillers, which were significantly higher than that produced from smaller ones. In the field experiment in 1999-2000, significantly lower number of tillers was produced in the plants from R-20 g or R-10 g compared with the plants from larger seed, and the plants from R-30 g, R-40 g and MR produced nearly the same number of tillers (Fig. 3). In the field experiment in 2003, nearly the same number of tillers was produced in the plants from R-20 g, R-30 g, R-40 g, R-50 g and MR (Fig. 3).

3. Number of leaves, leaf area and leaf dry weight of turmeric

In the greenhouse experiments, the number of leaves per plant increased with the increase in seed size (Fig. 4). In the first experiment (1999-2000) the plants from R-20 g and MR had a larger number of leaves, whereas in the second experiment (2003) the number of leaves was significantly largest in the plants from R-50 g followed by those from MR and R-40 g, compared to smaller seeds (Fig. 4). In the first field experiment, the number of leaves was markedly higher in the plants from R-30 g, R-40 g and MR than in those from R-10 g and R-20 g, whereas in the second experiment, the plants from R-20 g, R-30 g, R-40g, R-50 g and MR produced almost a similar number of leaves (Fig. 4). Leaf area, and dry weight of leaves and pseudostem increased with the larger seed rhizomes in both the greenhouse and field experiments (Table 1). The leaf area, and dry weight of leaves and pseudostem were highest in the plants from MR in greenhouse experiment, but they were highest in the plants

Table 1. Effects of seed rhizome size on the leaf area, and dry weight of leaves, pseudostem and rhizome of the plants harvested at 165 and 105 days after planting in glasshouse and field experiment, respectively in 1999-2000 cropping season.

	Greenhouse experiment				Field experiment			
Seed size (g seed^{-1})	Leaf area (cm^2 plant^{-1})	Leaf dry weight (g plant^{-1})	Pseudostem dry weight (g plant^{-1})	Rhizome dry weight (g plant^{-1})	Leaf area (cm^2 m^{-2})	Leaf dry weight (g m^{-2})	Pseudostem dry weight (g m^{-2})	Rhizome dry weight (g m^{-2})
R-5g	2483±376c	19.5±2.3c	15.8±1.5c	3.4±0.5d	-	-	-	-
R-10g	2666±248c	20.4±1.4c	16.5±1.3c	4.3±0.7d	3074±303d	39±2d	31±3c	25±1c
R-15g	4147±127b	26.2±0.9b	20.6±1.0b	5.7±1.0c	-	-	-	-
R-20g	4547±539b	26.9±3.5b	21.0±2.4b	7.1±0.7b	7199±642cd	67±5cd	50±5bc	32±2bc
R-30g	-	-	-	-	12995±1723bc	106±12bc	76±15b	43±4b
R-40g	-	-	-	-	21014±4645a	158±32a	120±35a	60±16a
MR	6042±537a	34.6±2.1a	26.0±1.0a	10.9±0.8a	9238±495bcd	79±3bcd	55±4bc	39±1b

R: daughter rhizome; MR: mother rhizome (48-52 g);—: experiment not conducted. Data are means±SD. Data were from 5 plants for each treatment in greenhouse experiment. In the field experiment, data were obtained from six plants for each replication and means were calculated, then means for the treatments were calculated from three replications. Means with the same letter within each column are not significantly different at 5% level, as determined by LSD test.

from R-40 g followed by R-30 g and MR in the field experiment.

4. Turmeric shoot biomass

In the 1999-2000 season, the shoot biomass at the first harvest (165 DAP in the greenhouse, 105 DAP in the field) increased with the increase in seed size in both the greenhouse and field experiments, and that in the greenhouse experiment was significantly larger in the plants from the seeds above 15 g than in those from smaller seeds (Fig. 5). In 2003, however, the shoot biomass in the greenhouse was larger in the plants from R-30 g, R-40 g, R-50 g and MR than in those from R-20 g (Fig. 5). In 1999-2000, shoot biomass in the field was largest in the plants from R-30 g and R-40 g but in 2003, it was largest in the plants from MR (Fig. 5).

5. Turmeric yield

Turmeric yield at first harvest 165 and 105 DAP in the greenhouse and field experiment, respectively increased with the increase of seed size in both the greenhouse and field experiments, and the plants from R-5 g~R-20 g produced a significantly lower yield than those from a larger R (Table 1). At final harvest, the yield was reduced significantly in the plants from R-5 g~R-15 g and was statistically similar in the plants from R-20 g and MR in the first greenhouse experiment (1999-2000), whereas in the second greenhouse experiment (2003), the plants from R-20 g, R-30 g, R-40 g, R-50 g and MR produced a similar yield (Fig. 6). Turmeric plants from R-40 g produced the highest yield followed by those from R-30 g, and the plants from MR had a significantly lower yield than those from R-30 g and R-40 g in the first field experiment, whereas in the second experiment MR had the highest yield, and the yield did not differ among the plants from R-20 g, R-30 g, R-40 g and R-50 g. However, yield increased somewhat with the increase of seed size.

Discussion

We found only a 5- to7-day difference in seedling emergence from the seed rhizomes of different sizes, but the difference was not significant because turmeric requires around 50 days to complete seedling emergence. Turmeric seedlings from larger seed rhizomes were healthier because larger seed rhizomes had larger buds. Not only the weight but also the diameter of seed rhizome is the factor for producing vigorous seedlings. It was observed that the rhizomes with a larger diameter had larger buds, which developed vigorous seedlings (data not presented). Larger seed rhizomes contain a larger amount of reserves that enhanced seedling growth, which ultimately resulted in a taller plant (Fig. 2). In tropical soda apple and spring wheat, Akanda et al. (1996), and Stougaard and Xue (2004) reported that larger seed produced longer coleoptiles, and had higher reserves, which improved seedling establishment. In the present study, the greater differences in plant height were observed among the seed rhizomes of different sizes during early growth stage of 135 days after planting, because the amounts of reserved nutrients effective in the initial plant growth stage were different. Thereafter, the plant height became similar in all plants from seed rhizomes of different sizes, because all plants were applied a similar amount of nutrients. However, as a whole, the plants from the seed rhizomes

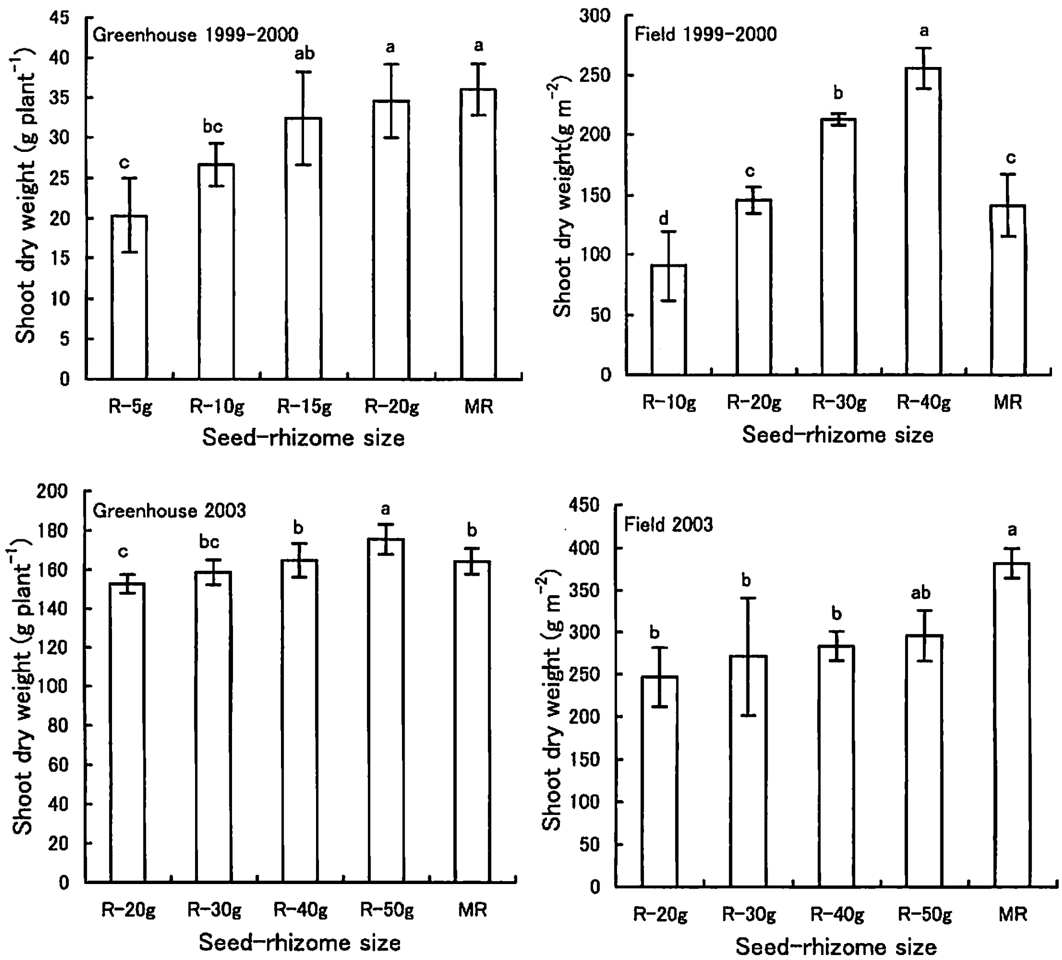

Fig. 5. Effects of seed rhizome size on shoot biomass of turmeric. R: daughter rhizome; MR: mother rhizome. Data are means±SD. Data were from 5 and 6 plants for each treatment in the greenhouse experiment 1999-2000 and greenhouse experiment 2003, respectively. For both the field experiments, data were from all plants for each replication and means for the treatments were calculated from three replications. Bars with the same letter are not significantly different at 5% level, as determined by LSD test.

below 20 g could not reach the plant height similar to that from larger seed rhizomes, and the plants from R-30 g, R-40 g, R-50 g and MR reached almost a similar height. At the initial stage, the difference in the number of leaves was not large because the seedlings emerged almost at the same time, but leaf size was bigger when the seed was larger. After the initial stage, the number of leaves increased as the seed size increased, because the plants from the larger seeds were longer and had a larger number of tillers. The shoots with a larger leaf number and larger leaf size received a higher solar energy for photosynthesis, which ultimately resulted in a larger shoot biomass (Fig. 2). This result is in agreement with the report of Sarker et al. (2001) on rice plant.

Shoot biomass of turmeric plants increased with increasing seed size in all the experiments, which was consistent with the results in wheat crop (Singh and Singh, 2003). But the shoot biomass of turmeric was similar and higher in the plants from R-20 g and MR in the greenhouse experiment in 1999-2000, and it was the highest in the plants from R-50 g followed by those from R-40 g, MR and R-30 g in the greenhouse experiment in 2003 (Fig. 5). Similarly, Santos et al. (1997) reported that shoot biomass of purple nutsedge was increased significantly by increasing seed tuber weight up to 0.75 g, and only slightly by a further increase in the tuber weight up to 1 g. In the field experiments, shoot biomass of turmeric increased markedly as the size of seed rhizomes increased because plants from larger seed rhizomes were healthier and taller (Fig. 1,2), and shoot damage caused by typhoon (September 22, 1999 (968.8 hPa, 35.2 m s^{-1}); August 7, 2003 (956.5 hPa, 27.4 m s^{-1}); September 19-20, 2003 (985.8 hPa, 18.4 m s^{-1})) was less and recovery was earlier when larger rhizomes were planted (data not presented). In our previous studies, the shoot biomass of turmeric increased as the tiller

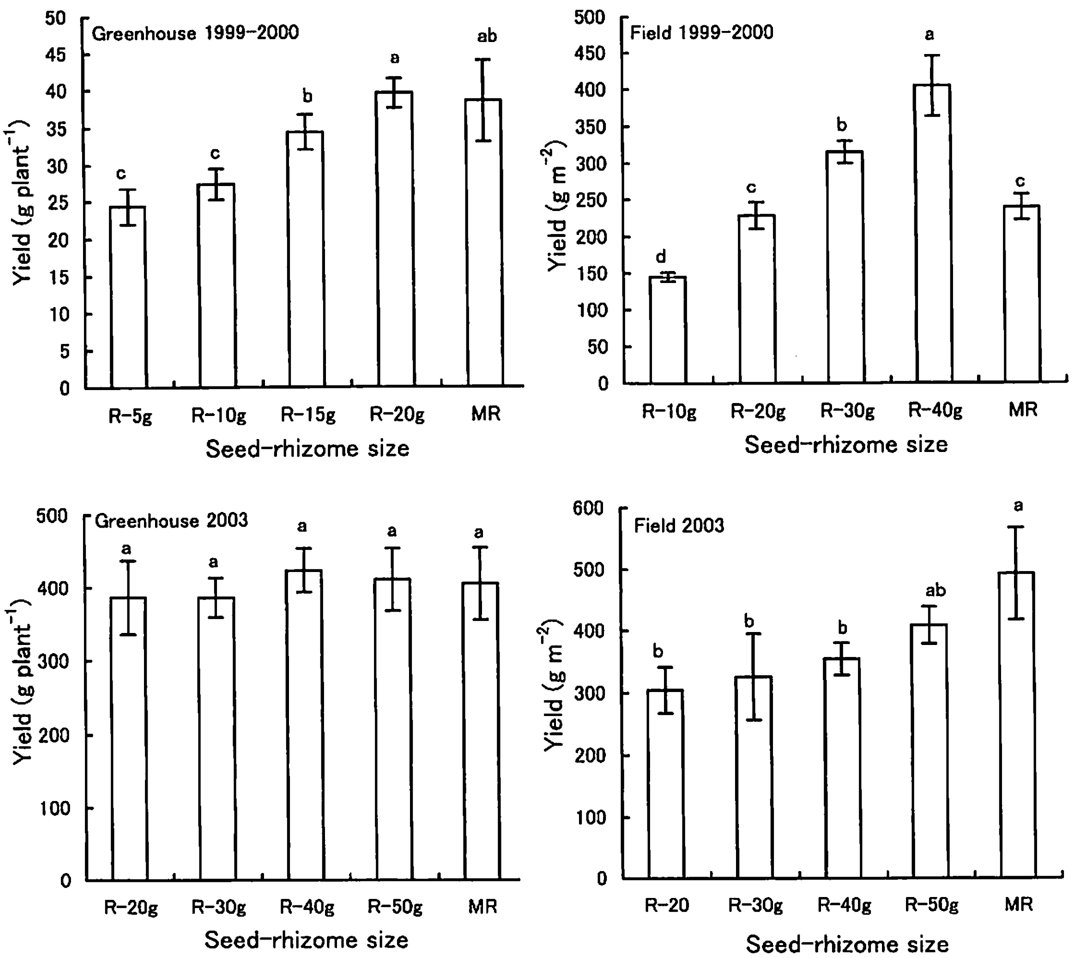

Fig. 6. Effects of seed rhizome size on final yield of turmeric. R: daughter rhizome; MR: mother rhizome. Data are means±SD. Data were from 5 and 6 plants for each treatment in the greenhouse experiment 1999-2000 and greenhouse experiment 2003, respectively. For both the field experiments, data were from all plants for each replication and means for the treatments were calculated from three replications. Bars with the same letter are not significantly different at 5% level, as determined by LSD test.

number and plant height increased, and a healthier shoot was less affected by typhoon and rapidly recovered, which ultimately resulted in a larger shoot biomass (Hossain et al., 2000; Ishimine et al., 2003, 2004).

The larger the seed rhizome, the higher the turmeric yield in most of the experiments due to larger shoot biomass (Fig. 6). However, as a whole, the yield was similarly higher in the plants from R-30 g~R-50 g, because they had a larger shoot biomass and showed similar shoot growth. This result was consistent with the results of Hossain et al. (2000) and Ishimine et al. (2003). In addition, plants from the larger seeds (R-30 g~R-50 g) had a bigger shoot base in all experiments, which produced a higher number of daughter rhizomes (data not presented). It was also observed that the plants from larger seed rhizomes R-30 g~R-50 g produced daughter rhizomes earlier in a higher number, which ultimately increased the yield of turmeric.

Stougaard and Xue (2004) found that the yield of spring wheat increased as the seed size increased up to 37 g (TKW), and further increase in seed size had little effect. Santos et al. (1997) also reported that the yield of purple nutsedge increased as the tuber size increased up to 0.75 g. From these results, it was thought that the yield of a crop plant increased as the seed size increased up to a certain level, and a further increase in seed size had little effect on the yield. The present experiment indicated that turmeric yield was highest when the seed rhizomes were R-30 g~R-50 g.

Shoot dry weight and yield of the plants from MR were significantly less than those of the plants from R-30 g and R-40 g in the first field experiment, because some plants developed from the daughter rhizomes attached to the MR. On the other hand, the shoot dry weight and yield were the highest in the plants from MR in the second experiment, because all plants developed directly from MR (Fig. 5, 6). These experiments suggested that seed mother rhizome should be free from daughter rhizomes. Shoot dry weight and yield in the second greenhouse experiment were around ten times greater than the first experiment (1999-2000) (Fig. 5, 6). This was because farmyard manure (cow dung) was used in the second experiment.

Weed biomass was not affected by seed size with 45 DAP, because canopy structure did not develop during this period. Thereafter, weed biomass was smaller when larger seed rhizomes were planted because they developed a better canopy structure. This result is consistent with the result of the experiment of Ishimine et al. (2003) in the field.

Conclusion

All the trials in this study showed that seedlings from R-30 g, R-40 g, R-50 g and MR were similarly healthy. Plants from R-30 g, R-40 g and R-50 g had almost the same height and number of tillers and leaves, which were significantly higher than those in the plants from the smaller seed rhizomes. Turmeric plants from R-30 g~R-50 g developed canopy structure earlier which ultimately reduced weed biomass. The plants from R-30 g~R-50 g were less affected by typhoon and they recovered faster, compared with the plants from smaller seed rhizomes. Shoot biomass was similar and significantly higher in the plants from R-30 g~R-50 g, compared with that of the plants from smaller seed rhizomes. The plants from R-30 g~R-50 g had a larger shoot base, which developed daughter rhizomes earlier in a higher number and had a similarly high yield in each experiment. The plants from MR had the highest shoot biomass and yield. On the other hand, the shoot biomass and yield were lower in the plants produced from the daughter rhizomes attached to the MR. The seed rhizome of 50 g must include secondary and tertiary daughter rhizomes, and the plants developing from secondary and tertiary daughter rhizomes result in a lower yield. In addition, the seed of 50 g was easily broken when planted. Not only the weight but also the diameter of seed rhizome is the factor for selecting good seeds of turmeric. The results of this study suggest that turmeric seed rhizomes should have a larger diameter and be within 30-40 g, and daughter rhizomes must be removed from the seed mother rhizome.

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