Effects of Slow Clinorotation on Growth and Yield in Field Grown Rice

Sagar S. Jagtap[1], Kondiram N. Dhumal[2], and Pandit B. Vidyasagar[1]

[1]*Biophysics Laboratory, Department of Physics, University of Pune, Pune, MH 411007 INDIA;* [2]*Department of Botany, University of Pune, Pune, MH 411007 INDIA*

Several studies concerning with the effects of microgravity conditions on plant growth have already been carried out using spacecrafts (Abilov et al., 1986; Aliyev et al., 1987; Kordyum, 1994). Clinostats have been used to compensate for the unilateral influence of gravity for a long period of time in the field of plant physiology. Several experiments have been carried out on a slow rotating (ranging from 0.25 – 3 rpm) clinostat to study the effects of clinorotation also termed as simulated microgravity on plant growth and development.

Plants, especially cereal crops, are the basis for human being to accomplish the food requirement; hence, it is of great importance to study the influence of microgravity on growth and development in food grain crops. Earlier studies carried out on the effects of clinorotation on plants showed that plant growth, morphology, chlorophyll content was affected by slow clinorotation (Sievers et al., 1996; Sack 1997; Jagtap et al., 2010). Several reports have described the effects of clinorotation on physiology of plants and cell biology (Hilaire et al., 1995a), protein expression (Piastuch and Brown, 1995), carbohydrate metabolism (Brown and Piastuch, 1994, Obenland and Brown, 1994), calcium distribution (Hilaire et al., 1995b) and the cell cycle (Legue et al., 1992). Colla et al. (2007) showed that morphological and growth characteristics such as growth, yield, and quality of the dwarf tomato variety 'Micro-Tom' were modified during clinorotation treatment. They also showed that clinorotation-exposed seeds were viable and subsequent generations might be obtained in microgravity (Colla et al., 2007). In most of the studies, seeds were germinated and grown under clinorotation. As per our knowledge, there are no reports on the effects on changes in growth, yield, and soluble protein content of seeds from plants that were grown from clinorotated seeds. In the present investigation, effects on growth, various yield attributes as well as seed nutrient contents such as starch, carbohydrates and protein content in plants raised from rice seeds (*Oryza sattiva* L) exposed to slow clinorotation (2 rpm) for 12 days and grown in the field at normal (1 g) condition were studied.

Authentic seeds of rice (variety PRH-10) were procured from National Seeds Corporation, New Delhi, India. Total 600 mature seeds of uniform size were selected and surface sterilized by using 0.5% fungicide (Uthane M-45® manufactured by United Phosphorus Limited), washed 4-5 times with distilled water (D/W) to remove traces of fungicide, and soaked in D/W for 24 h. After 24 h soaking, seeds were removed from D/W and blotted dry with blotting paper to prevent germination during clinorotation. For clinorotation treatment, 300 seeds were placed in cavities made in disc shaped thermacol on a periphery of a circle of radius 1.5 cm. On each piece of

Figure 1. Plant growth in control and clinorotated samples. The Control plants are shown on the left and the plants grown from clinorotated seeds on the right.

Figure 2. Number of panicles in control (left, blue bowl) and the plants grown from clinorotated seeds (right, red bowl).

thermacol 25 seeds were placed. About 12 such thermacol discs containing 300 seeds separated with cotton were placed in two Perspex® beakers and then clinorotated for 12 days continuously at 2 rpm resulting in g ~ $7x10^{-5}$ (Jagtap et al., 2010) in dark under ambient conditions of temperature (23±5 °C) and humidity (50±10 %). Remaining 300 seeds at same environmental conditions but without clinorotation were used as control. After the treatment, clinorotated and control seeds packed in polythene bags were stored at room temperature, and sent to Agricultural Research Station, Shirgaon, District-Ratnagiri (Maharashtra) India. On 15^{th} day from the date of clinorotation treatment, seeds were sown in the field at Agricultural Research Station, Shirgaon. Seedlings were transplanted on 40^{th} day after sowing (DAS). All the measurements such as plant height, number of productive tillers per plant, length of panicle, number of tassels, number of filled grains per panicle, weight of 1000 filled grains, biological yield per plant, and harvest index were recorded at the time of harvest, i.e. on 80^{th} day after transplanting. The results of present study revealed that the exposure of seeds to slow clinorotation for 12 days had caused significant improvement in paddy yield and protein content over control.

The appreciable changes were observed in various yield attributes. Number of productive tillers per plant, height of tiller from soil level (Figure 1), length as well as number of panicle (Figure 2), number of tassels, number of filled grains, total grain weight per plant, weight of 1000 grains, and economic yield per plant was significantly increased with clinorotation in rice (Table 1).

Observations indicate that number of productive tillers per plant, height of tiller from soil level, length as well as number of panicles, and also number of tassels increased in clinorotated samples. Total chlorophyll content was also enhanced by ~ 28% in clinorotated samples. Results of present study for the first time revealed about ~ 6 % increase in protein content of rice seeds of plants raised from seeds exposed to slow clinorotation (2 rpm) for 12 days and grown in field which is highly important and having a dietary significance (Table 1). However, there was ~ 1% and ~ 5 % reduction in carbohydrate and starch content respectively. It is well documented that plants with high chlorophyll concentration exhibit higher rates of photosynthesis under low light relative to plants with less chlorophyll pigment concentration (Bjorkman, 1981; Boardman, 1977). Therefore increase in growth and various yield attributes in this study may be due to an increase in chlorophyll *content in clinorotated sample.*

Table 1. Effects of clinorotation on different yield attributes in field grown rice

Attribute	Control	Clinorotated
No. of productive tillers / plant	14.5±0.7	18.0±0.7*
Height of tiller from soil (cm)	40.0±1.7	42.4±1.3**
Number of tassels	8.0±0.7	10.4±0.6*
Length of panicles (cm)	18.7±0.3	23.3±0.3*
Number of grains per panicle	71.6±0.5	105.4±0.6*
Filled grains per panicle	34.6±0.8	46.2±0.1*
Number of filled grains per plant	493.6±12.9	828.5±17.3*
Total grain weight per plant (g)	14.4±0.2	23.3±0.1*
Weight of 1000 grains (g)	20.4±0.01	20.8±0.02*
Biological yield per plant (g)	18.0±0.6	24.3±0.9*
Harvest Index	80.1±3.4	95.9±3.3*
Total Chl content (3rd leaf)	5.71±0.9	7.97±1*
Protein content	11.10%	11.80%
Carbohydrate (Total sugars)	66.90%	66.40%
Starch	54.60%	51.60%
Embryo viability (harvested seeds)	~ 97%	~ 97%

In comparison with these observations the earlier studies have shown that the 'Micro-Tom' plants grown under simulated microgravity exhibited a spreading growth and an increase in internodal length. The number of flowers per plant was significantly increased by 32% in clinorotated plants in comparison to those grown in absence of clinorotation. However, total fruit yield, small fruit yield, leaf area, leaf dry weight, fruit dry weight, total dry weight were decreased significantly in the clinorotated tomato plants than those grown in the control treatment (Colla et al., 2007). Also the studies carried out by Hilaire et al. (1996) confirmed that slow clinorotation had influenced morphology and ethylene production, i.e. metabolic process in soybean seedlings. However, the present study differs in one respect; that is, the seeds were exposed to clinorotation and plants were grown under normal (1 g) condition. Hence the observations in the present study show a marked difference from the studies reported earlier.

Also the results of tetrazolium test performed on rice seeds from harvested plants showed ~ 97 % embryo viability in control as well as clinorotated seeds suggesting that these seeds have mature embryo and can be used further for sowing to raise new crop. Similar results were obtained by Colla et al. (2007) showing that seeds formed under simulated microgravity proved to be biologically and functionally complete, showing that 'Micro-Tom' plants could realize complete ontogenesis, from seed to seed in microgravity (Colla et al., 2007).

In the present investigation seeds exposed to clinorotation before germination were sowed under normal (1 g) conditions fifteen days after the exposure, and compared directly to seeds with identical heritage that had not been subjected to clinorotation. Comparisons of the development of seeds exposed to clinorotation to the development of the control seeds showed statistically significant differences in the two sets as the plants matured. These data suggest that the physiological differences between the two sets of mature plants are related to the exposure of the seeds to clinorotation, as all other aspects of the seed treatment and culture were controlled between the two sets. This is a novel observation and may have future benefit for improving crop productivity of various cereals, including rice.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge authorities at the Agricultural Research Station, Shirgaon, District-Ratnagiri (Maharashtra) India for performing field trials of our experiments. Financial support was provided by the Department of Science and Technology (DST), Govt. of India under the scheme (GoI-A-563).

REFERENCES

Abilov, Z. K., Alekperov, U. K., Mashinskiy, A. L., and Aliyev, A. A. 1986. The morphological and functional and functional state of the photosynthetic system of plant cells grown for varying periods under spaceflight conditions. *USSR Space Life Sci Digest,* 8: 15-18.

Aliyev, A. A., Abilov, Z. K., Mashinskiy, A. L., Ganiyeva, R. A., and Ragimova, G. K. 1987. The ultrastructure and physiological characteristics of the photosynthesis system of shoots of garden pea grown for 29 days on the 'Salyut-7' space station. *USSR Space Life Sci Digest*, 10: 15-16.

Bjorkman, O. 1981. Responses to different quantum flux densities. In: Physiological Plant Ecology I. Responses to the Physical Environment. *Encyclopedia of Plant Physiology New Series*, (O. L. Lange, P. S. Nobel, C. B. Osmond & H. Ziegler, Eds.), Vol. 12A. pp. 57-107

Boardman, N. K. 1977. Comparative photosynthesis of sun and shade plants. *Ann Rev of Plant Physiol.* 28: 355-377.

Brown, C.S. and Piastuch, W.C. 1994. Starch metabolism in germinating soybean cotyledons is sensitive to clinorotation. *Plant Cell Environ*. 17: 341-344.

Colla, G., Rouphael,Y., Cardarelli, M., Mazzucato, A., and Olimpieri, I. 2007. Growth, yield and reproduction of dwarf tomato grown under simulated microgravity conditions. *Plant Biosystems* 141(1): 75 – 81.

Hilaire, E., Paulsen, A.Q., Brown, C.S., and Guikema, J.A. 1995a. Effects of clinorotation and microgravity on sweet clover columella cells treated with cytochalasin D. *Physiol Plant*. 95: 267-273.

Hilaire, E., Paulsen, A.Q., Brown, C.S., and Guikema, J.A. 1995b. Microgravity and clinorotation cause redistribution of free calcium in sweet clover columella cells. *Plant Cell Physiol*. 36: 831-837.

Hilaire, E., Peterson B. V., Guikema J. A., and Brown C. S. 1996. Clinorotation affects morphology and ethylene production in soybean seedlings. *Plant Cell Physiol*. 37(7): 929-934.

Jagtap S. S., Awhad R. B., Santosh B., and Vidyasagar P. B. 2010. Effects of clinorotation on growth and chlorophyll content of rice seeds. *Microgravity Sci Technol*. DOI 10.1007/s12217-010-9222-9.

Kordyum, E. L. 1994. Biology of plant cells in microgravity and under clinostating. *Int Rev Cytol*. 171: 1-78.

Obenland, D.M. and Brown, C.S. 1994. The influence of altered gravity on carbohydrate metabolism in excised wheat leaves. *J Plant Physiol*. 144: 696-699.

Piastuch, W.C. and Brown, C.S. 1995. Protein expression in *Arabidopsis* thaliana after chronic clinorotation. *J Plant Physiol*. 146: 329-332.

Sack, F. D. 1997. Plastids and gravitropic sensing. *Planta*, 203: S63-S68.

Sievers, A., Buchen, B., and Hodick, D. 1996. Gravity sensing in tip-growing cells. *Trends Plant Sci*. 1: 273-279.

Yoshioka R., Soga K., Wakabayashi K., Takeba G., and Hoson T. 2003. Hypergravity-induced changes in gene expression in *Arabidopsis* hypocotyls. *Adv Space Res*. 31(10): 2187-2193.