The Journal of Agricultural Sciences
Vol. 11, No. 1, January 2016. Pp 42 - 52

Vegetative Growth and Yield Associated Flowering Time Variation in Sri Lankan Rice "*Hondarawala*"

E. U. U. Rathnathunga[1], S. G. J. N. Senanayake[2], N. Dissanayake[3], S. Seneweera[4] and S. Geekiyanage[2*]

Received : 09th June 2015 / Accepted : 21st Septeber 2015

ABSTRACT

Breeding new varieties adaptable for changing climate is an essential need in sustainable rice production. Around 2000 Sri Lankan rice accessions at Plant Genetic Resources Centre (PGRC), Sri Lanka have not been fully characterized for the yield potential and sensitivity to mild photoperiodic differences for days to flowering (DF). DF is a candidate key determinant in yield components in rice and understanding the physiological and molecular nature for DF is important to manipulate crop yield through breeding programmes. The objective of this study was to assess the genetic diversity of 15 Hondarawala accessions from PGRC using selected 37 morphological characters and DF. DF varied from 58-189 days while accession number 3988 did not flower until 200th day of seed germination. Principal Component Analysis (PCA) revealed that four principle components (PA) explained 86.5% of total observed variation. Variation of DF positively associated with most of morphological characters of vegetative growth while a few characters were negatively associated. In the dendogram, 10 clusters formed at rescale distance of 5. Widely variable DF accessions distributed among clusters.

Keywords: *Days to flowering, genetic diversity, morphological characters, Sri Lankan rice*

INTRODUCTION

Rice is the most important food crop in Sri Lanka contributing to more than 40% of daily calorie requirement. There is a wide variation in DF among Asian origin rice which is distributed in a range of agro-ecological zones in the region (Lu and Chang 1980). DF had affected the ecological adaptation of rice (Izawa, 2007). Sri Lankan traditional rice germplasm which is conserved at PGRC, Sri Lanka, consists of around 2000 accessions. Sri Lankan traditional rice germplasm is relatively a large genetic resource in a geographically small island of Sri Lanka. There is a genetic diversity among accessions as they exhibit a wide variation in morphology and DF. Reasonable information on genetic and molecular mechanism of DF in rice is available (Yano and Izawa, 2005). However, Sri Lankan rice germplasm has rarely been used in flowering time studies except for the work by Chandrarathna (1964) mainly.

Increased and stable rice production is required for increasing population during the era of climate change. New adaptation strategies are needed to develop new varieties to meet these challenges. The genetic potential of Sri Lankan traditional rice has not been completely characterized and exploited for its potential contribution in breeding for yield increment. DF in rice is controlled by both genetic factors and environmental signals. Photoperiod and temperature are the two main environmental signals that determine the flowering time in rice (Song*et al*, 2012).

[1] *Board of Study in Agriculture, Faculty of Graduate Studies, University of Ruhuna, Matara, Sri Lanka.*
[2] *Department of Agricultural Biology, Faculty of Agriculture, University of Ruhuna, Mapalana, Kamburupitiya, Sri Lanka.*
[3] *Ministry of Agriculture, "Govijana Mandiraya", Rajamalwattha, Battaramulla, Sri Lanka.*
[4] *Centre for Systems Biology, University of Southern Queensland, Toowoomba, QLD 4350, Australia.*

Molecular basis for DF had been explained through many quantitative trait loci (QTLs): *Hd1* (Yano *et al*, 2000), *Hd3a* (Kojima *et al*, 2002), *Ehd1* (Doi*et al*, 2004), *Ghd7* (Xue*et al*, 2008), *RFT1* (Komiya *et al*, 2002). Matsuzaki*et al*, (2015) have demonstrated that the circadian clock is a regulatory network of multiple genes that retains accurate physical time of day by integrating the perturbations on individual genes under fluctuating environments in the field.

It is evident that different temperatures (of low country and hill country) in different ecological regions in Sri Lanka affect DF of rice. Effect of temperature at different phases of rice growth has not been completely studied. Among the known flowering time genes of rice, *Ehd1* and *Hd1* together control panicle development (Endo-Higashi and Izawa, 2011). *DTH8,* a QTL for DF is located on chromosome 8, also regulate yield potential and plant height (Wei *et al*, 2010). However, it is not known how these interact with each other on the crop yield potential. When three Sri Lankan traditional rice genotypes were grown under long day (LD), day neutral (DN) and short day (SD) photoperiods, days to flowering were increased under LD while there was an inverse relationship between enhanced vegetative growth and yield (Geekiyanage, 2012). The above traditional rice genotypes may represent the general response of Sri Lankan traditional rice germplasm on relationship between DF and, vegetative growth and yield. To test the relationship between DF and, vegetative growth and yield components of a Sri Lankan traditional rice in which several accessions are listed for one variety at PGRC, we selected *Hondarawala* variety which consisted of 15 accessions. As *Hondarawala* had been identified as suitable for low phosphorus field conditions, it had been exploited in breeding programmes for new improved varieties at IRRI.

In Sri Lanka, the cultivation of traditional rice varieties had largely eliminated from regular farmer field due to introduction of new improved varieties claiming desired plant type and yield. Currently, the maximum yield potential has been achieved in improved rice while there are needs for improvement of the rice quality. Therefore genetic resources of traditional rice must be utilized for further yield increase strategies for both yield and quality enhancement. We used the accessions of same variety *Hondarawala* with different DF for the experiment. The objectives of the experiment were to analyze the variation of DF, vegetative growth and yield among accessions and relationships between DF and vegetative growth and yield.

MATERIALS AND METHODS

Rice Accessions

Fifteen accessions of Sri Lankan traditional rice variety *Hondarawala* (Accession numbers: 3906, 6198, 4070, 4071, 3988, 3678, 3850, 3977, 6199, 6690, 6428, 4243, 3521, 3528, 6200) were obtained from Plant Genetic Resources Center (PGRC), Sri Lanka.

Field Experiment

Rice accessions were grown at Rice Research and Development Institute, Batalagoda, Sri Lanka (in IL1 agro ecological zone, latitude 7° 29’ 12” N and longitude 80° 21’ 53” E with a height above MSL 137m). Average ambient temperature during the cropping season was 30 °C and the soil was Dark brown earth (DBE). Each replicate consisted of 3 m long 3 row-plots with 9 plants: 20 cm x 20 cm within and between rows and 40 cm between plots in a Completely Randomized Design (CRD) with 4 replicates. The experiment was carried out in wet season during north eastern monsoon (*Maha*), 2012/2013 during which day length varies 11-11.5 hours in Sri Lanka. The seeds were sown in the upland nursery bed in December, 2012 with 15cm spacing in between each accession. Seedlings were transplanted by 21-days. Fertilizer application, pest and disease management and weed control were according to the recommendation by Department of Agriculture, Sri Lanka. The basal dressing of urea, TSP and MOP (as in the ratio of N: P: K) was applied during land preparation. Top dressing of 25, 50 and 50 kg/ac of urea were applied at 2 weeks, 5 weeks and 7 weeks of planting respectively. Manual weeding was done at regular intervals and the competition from weeds was kept minimal. Approximately permanent standing water level of 5 cm was maintained throughout the experiment.

Evaluation of morphological traits

Thirty seven morphological characters; 15 quantitative and 21 qualitative characters and DF were recorded (Table: 01). With respective to each character in a given accession, average value of replicates was considered for analysis. Data were collected at heading and at harvest of each variety. Measurement techniques were based on descriptors of rice published by the Team of NRC research project 12-129 (2014), International Rice Research Institute (1980 and 2007) and PGRC (2006).

Statistical analysis

Data were analyzed using PCA with correlation matrix through SPSS software (version 20), IBM, USA to define the patterns of variation between all explanatory variables. Grouping of variables into PCs was noted and thereby the dimension of the data set reduced. The 14 accessions which flowered during the experimental period of 200 days were clustered using Hierarchical Cluster analysis through SPSS software (version 20); IBM, USA which grouped and sorted the closely related accessions into clusters, using the first four PC scores of varieties. Measure of dissimilarity was the Euclidean distance and the clustering method was Ward's linkage. The number of clusters was determined at the rescaled distance of 5.

.

RESULTS AND DISCUSSION

Variation in DF among **Hondarawala** *accessions*

DF and quantitative morphological charactersof vegetative growth and yield components were largely varied among all *Hondarawala* accessions (Table: 02 and 03). DF among 15 accessions varied from 58-189 day while accession number 3988 did not flower until 200th day of seed germination. Seeds had been germinated in late January, 2013 which was the end of mild short day season in Sri Lanka under natural field conditions during which the photoperiod changes from short day to long day. As a result, the inductive photoperiod durations may have changed over time. Vegetative growth phase, reproductive phase and ripening phase are the 3 main phases of rice growth (Vergara and Chang, 1985). In vegetative growth phase, there are 2 sub-phases as basic vegetative phase (BVP) which is the photoperiod insensitive vegetative phase and photoperiod sensitive phase (PSP). BVP is a highly variable time duration which may be genetically controlled (Chandrarathna, 1964). In *Hondarawala* accessions DF varied from 58 to 200+ days indicating that juvenile period of BVP is variable among them. Additionally, effect of temperature variation during the period may have played a role in determining the DF.

Duration from panicle initiation (PI) to flowering is also affected by photoperiod (Coolhaas and Wormer, 1953; Best, 1961; Janardhan and Murty, 1967). Based on results in a rice cultivar, Collinson *et al*., (1992) found that PI occurred when about 80% of the PSP had elapsed in a rice cultivar. These findings suggest that wide variation of DF among accessions and non-flowering at non-inductive photoperiod must be highly determined by the genetic factors of each accession.

Table 01: The quantitative and qualitative characters measured during the experiment

Character	Abbreviation
Plant height at maturity	PH
Culm length at maturity	CL
Culm number at maturity	CN
Culm diameter at maturity	CD
Panicle length at maturity	PL
Grain length at maturity	GL
Grain width at maturity	GW
Leaf number at maturity	LN
Leaf length at maturity	LL
Leaf width at maturity	LW
Ligule length at maturity	LiL
Root length at maturity	RL
Shoot weight at maturity	SW
Panicle weight at maturity	PW
Plant height at vegetative stage	PHV
Culm number at vegetative stage	CNV
Leaf angle	LA
Flag leaf angle	FLA
Leaf blade puberscence	LBP
Leaf blade Colour	LBC
Leaf senescence	LS
Ligule colour	LiC
Ligule shape	LiS
Internode color	IC
Culm angle	CA
Culm strength	CS
Panicle type	PT
Panicle exertion	PE
Panicle axis	PA
Secondary branching	SB
Awning after full heading	AP
Awn colour	AC
Apiculus colour	ApC
Lemma and palea colour	LPC
Lemma and palea puberscence	LPP
Pericarp colour	PCC
Sterile lemma colour	SLC

Table 02: Descriptive statistical explanation of the variation of quantitative characters among the accessions of Sri Lankan traditional rice variety *Hondarawala*.

Character	Unit	Range	Average	Standard Deviation
DF	Days	58 – 200+	111.50	39.32
PH	cm	119.68 – 198.25	163.14	20.16
CL	cm	99.10 – 155.00	119.83	14.16
CN	Number	10 – 42	18.48	8.57
CD	mm	4.5 – 6.5	5.80	0.99
PL	cm	5.70 – 28.50	23.19	5.82
GL	mm	6.8 – 14.8	7.50	0.64
GW	mm	2.5 – 4.0	3.10	0.44
LN	Number	30 – 148	69.52	20.79
LL	cm	42.46 – 75.90	62.17	9.41
LW	mm	9.4 – 14.4	11.77	1.30
LiL	cm	0.70 - 2.68	1.77	0.59
RL	cm	11.5 – 30.0	20.09	5.42
SW	g	93.33 – 415.93	166.62	65.50
PW	G	2.48 – 44.90	14.17	11.75
PHV	Cm	121.00 – 157.20	142.89	11.75
CNV	Number	11 – 23	16.81	2.94

Table 03: Variation of quantitative characters of Sri Lankan traditional rice variety *Hondarawala* within clusters derived through Ward's linkage method.

Cluster Number	PGRC accession number	Quantitative Character							
		DF	PH (cm)	CN	LN	LL (cm)	LiL (cm)	LW (mm)	PW (g)
1	3977	68	129.3	14	71	50.4	0.7	12.2	15.1
	6199	96	156.3	13	55	64.7	2.1	13.4	10.0
2	6428	58	119.7	17	67	42.5	1.7	11.0	23.1
3	3850	131	180.5	19	57	66.9	2.1	11.2	6.8
	3521	189	172.7	23	91	67.6	1.6	11.2	9.9
4	6690	119	175.8	29	114	68.4	2.3	12.0	7.9
5	3906	79	160.0	16	30	66.8	1.2	12.8	18.2
6	3528	186	172.0	42	39	75.9	0.7	11.2	13.2
7	4243	99	149.0	24	81	56.9	2.1	11.4	44.9
8	6200	82	173.3	10	59	50.5	1.8	14.4	30.3
9	6198	141	198.3	16	78	73.8	2.5	9.4	2.5
	4070	104	165.5	13	63	58.5	1.9	10.0	6.8
	4071	103	165.8	13	63	64.1	1.6	12.0	4.9
10	3678	106	166.0	13	72	63.3	2.7	12.6	4.9
*	3988	200+	160.3	15	39	63.4	0.9	11.2	-

*Accession number 3988 of which days to flowering exceeded the experimental period of 200 days was not included in the Cluster Analysis.

Relationship between days to flowering on variation in qualitative morphological characters

Except for the colour of ligule, all other 20 qualitative morphological characters were varied among accessions (Table: 04). Occurrence of heavy secondary branching in the panicle was observed in the longest DF accessions of 3528 and 3521.

Several workers of Yu *et al*., (1995), Yoshimura *et al*. (2001), Rutger and Mackill (2001), Rutger and Tai (2005) had reported that genes for hairs on rice leaf and hull are linked: According to Hu *et al*., (2013) all glabrous leafy rice produced glabrous hulls while hairy leafy rice produced hairy hulls. However, all *Hondarawala* accessions produced pubescent hulls and glabrous or pubescent leaves irrespective of DF variation indicating a genetic diversity of *Hondarawala* for leaf and hull pubescence. Further, a variety of pericarp colours and lemma and palea colours was observed indicating the allelic richness among accessions.

There were awns in all seeds only in one accession while others were without awns or partly awned. DF did not have a relationship with the presence of awns (Table:04).

Relationship between days to flowering on quantitative morphological characters

The correlation analysis revealed that there were strong significant positive correlations between DF and morphological characters of PH, CL, LL, RL, SW, PHV, LN and CNV while LW and PW were negatively correlated with DF (Table: 05). DF among accessions was a major determinant in quantitative morphological characters and yield components. Delayed flowering time increased the vegetative growth and reduced the panicle weight. Similarly, in our preliminary studies with Sri Lankan traditional rice varieties of *Devaraddili* and *Kohu Ma wee* under SD, LD and DN conditions, *Deveraddlili* and *Kohu Ma wee* did not flower by 200th at under LD condition and tiller number was significantly increased. Under DN condition, DF delayed in contrast to SD and yield was reduced (Geekiyanage *et al*, 2012). Tehrim *et al* (2012) had reported that DF of different rice genotypes was positively associated with days to maturity and straw yield per plant while DF negatively associated with seed setting percentage and harvest index.

In an experiment on photoperiodic effect fewer than four combinations of genetic compositions of *Hd1* and *Ehd1*, *Hd1* expression in non-functional *hd1* and *ehd1* background under LD increased the DF and tiller number with reduced spikelet number (Endo-Higashi and Izawa, 2011). Although genetic factors of the accessions have not been revealed, our observation during this experiment supports the above report as DF negatively correlated with total panicle weight. Although Endo-Higashi and Izawa (2011) reports that *Ehd1* and *Hd1* together suppress number of panicles and number of spikelets under SD with the shortest DF, in *Hondarawala* accessions, short DF increased the panicle weight (Table:03) indicating a different genetic control in flowering time.

Principal Component Analysis and Cluster Analysis

First four PCs explained 86.5% of total observed variation. (Table: 06). In PCA, most of the morphological characters of vegetative growth (PH, CN, LN, LL, RL and LL) which were affected by DF, included in simultaneous PCs with complex structures. Four PCs were rearranged removing the complex structures. Variation in DF among accessions was clearly exhibited within each cluster.

In the Hierarchical Cluster Analysis, ten clusters were formed at rescale distance of 5 (Figure: 01). DF varied within each cluster (Table: 03). At rescaled distance less than 5 even, there were 3 clusters with more than one accession in each (Figure: 01): Accessions 3977 and 6199 are grouped in one such cluster, except for LW, quantitative characters of DF, PH. LN, LL and

PW, and qualitative characters of LBP, PT, and PA were different from each other (Table: 03 and 04). Accession numbers 3850 and 3521 in third cluster were different to each other by quantitative characters of DF, PW and LN and qualitative characters of AC, AP, LPC, and PCC. Accession numbers 4070 and 4071 in 9th cluster were almost similar to each other while accession 6198 was different in most of qualitative and quantitative characters including DF.

Table 04: Variation of qualitative characters within clusters derived through Ward's linkage method.

Cluster number	PGRC accession number	Qualitative Character																				
		DF	LA	FLA	LBP	LBC	LS	LiC	LiS	IC	CA	CS	PT	PE	PA	SB	AP	AC	ApC	LPC	LPP	PCC	SLC
1	3977	68	Interm:	Horizontal	Interm:	Pale green	Interm:	White	2-cleft	White	Erect	Moderately strong	Interm:	Well	Droopy	Light	Absent	Absent	Brown	Brown:[a]	Long	Brown:[c]	Short or Medium
	6199	96	Erect	Interm:	Glabrous	Green	Interm:	White	2-cleft	White or Purple	Erect	Moderately strong or Interm:	Compact	Moderately well	Straight	Light	Absent	Absent	Brown	Brown:[a]	Long	Brown	Medium4
2	6428	58	Interm:	Erect	Interm:	Green	Interm:	White	2-cleft	White	Erect	Weak					Absent	Absent	Straw	Brown:[a]	Long	Brown	
3	3850	131	Horizontal	Interm:	Glabrous	Pale green	Early and fast	White	2-cleft	White or Purple	Interm:	Weak					Short and partly	Straw	Straw	Straw	Long	Red	
	3521	189	Horizontal	Erect	Interm:	Green	Early and fast	White	2-cleft	White	Interm:	Interm:	Compact	Moderately well	Straight	Heavy	Absent	Absent	Straw	Brown:[a]	Long	Brown	Short
4	6690	119	Erect	Erect	Interm:	Green	Late and slow	White	2-cleft	White	Interm:	Interm:	Interm:	Moderately well	Droopy	Light	Absent	Absent	Straw	Brown:[a]	Short	Brown:[c]	Medium
5	3906	79	Erect	Erect	Interm:	Green	Interm:	White	2-cleft	Purple	Interm:	Interm:					Short and partly	Gold	Gold	Brown:[b]	Long	Brown:[c]	
6	3528	186	Erect	Erect	Glabrous	Pale green	Interm:	White	2-cleft	Purple	Erect	Interm:	Interm:	Moderately well	Droopy	Heavy	Absent	Absent	Gold	Brown:[a]	Long	Brown	Short
7	4243	99	Horizontal	Interm:	Glabrous	Pale green	Interm:	White	2-cleft	White	Erect	Strong					Long and fully	Straw	Straw	Brown:[a]	Long	Brown:[a]	
8	6200	82	Erect	Erect or Interm:	Glabrous	Pale green	Interm:	White	2-cleft	Purple	Erect	Strong					Absent	Absent	Gold	Brown:[a]	Long	White	
9	6198	141	Erect or Horizontal	Erect	Glabrous	Pale green	Early and fast	White	Acute	Purple	Open	Moderately strong	Compact	Well	Straight	Light	Absent	Absent	Gold	Brown:[a]	Long		Short
	4070	104	Horizontal	Erect	Interm:	Dark green	Intermedi ate	White	Acute	Purple	Erect	Moderately strong	Compact	Well	Straight	Light	Absent	Absent	Straw	Straw	Short	Red	Short
	4071	103	Erect or Horizontal	Interm:	Glabrous	Pale green	Early and fast	White	2-cleft	Purple	Erect	Interm:	Compact or Interm:	Moderately well	Droopy	Light	Short and partly	Gold	Straw	Straw	Long	Red	Short
10	3678	106	Erect	Interm:	Glabrous	Pale green	Late and slow	White	2-cleft	White	Erect	Weak	Interm:	Moderately well	Droopy	Light	Short and partly	Straw	Straw	Brown:[a]	Long	Light brown	Short
*	3988	200+	Erect	Erect	Interm:	Pale green	Late and slow	White	2-cleft	White	Erect	Interm:	-	-	-	-	-	-	-	-	-	-	-

Interm: - Intermediate
a. Brownish black/ b. Brown furrows on gold background/ c. Brown seed coat with white strip

*Accession number 3988 of which days to flowering exceeded the experimental period of 200 days was not included in the Cluster Analysi

Table 05: Correlation among the quantitative characters within accessions of Sri Lankan traditional rice variety *Hondarawala*.

	Character	DF	PH	CL	CN	CD	PL	GL	GW	LN	LL	LW	LiL	RL	SW	PW	PHV	CNV
Correlation	DF	1.000	.650*	.428*	.656*	.266	-.061	-.161	-.216	.145	.772*	-.403*	-.025	.606*	.591*	-.365*	.345*	.436*
	PH		1.000	.390*	.153	.150	-.125	.351*	-.116	.106	.779*	-.192	.426*	.447*	.342*	-.457*	.600*	.010
	CL			1.000	.506*	.131	.318*	.057	.167	-.590*	.499*	.106	-.422*	-.216	.128	.161	.256	-.227
	CN				1.000	.336*	.139	-.386*	.028	.085	.490*	-.276	-.330*	.172	.768*	.070	.081	.608*
	CD					1.000	.139	.403*	.201	.323*	-.043	.023	-.216	-.088	.262	.195	.177	.268
	PL						1.000	.034	.558*	-.166	-.190	.056	-.471*	-.361*	.080	.488*	-.096	-.214
	GL							1.000	.514*	.121	-.190	.117	.326*	-.192	-.163	.092	.504*	-.279
	GW								1.000	.097	-.367*	.113	.084	-.387*	.100	.683*	.280	.011
	LN									1.000	-.040	-.225	.462*	.450*	.541*	-.064	.359*	.606*
	LL										1.000	-.261	.120	.536*	.406*	-.539*	.289	.137
	LW											1.000	-.088	-.280	-.373*	.295	.054	-.123
	LiL												1.000	.294	.119	-.173	.451*	.207
	RL													1.000	.464*	-.757*	.076	.518*
	SW														1.000	-.107	.313*	.774
	PW															1.000	.142	-.077
	PHV																1.000	.089
	CNV																	1.000

* > 0.3 , significant correlation (+) positive, (-) negative

Table 06: First four PCs on variation among accessions of Sri Lankan traditional rice variety *Hondarawala*

PC	PC 1	PC 2	PC 3	PC 4
Contribution to variation	31.7 %	23.8 %	17.8 %	13.2 %
Composition of characters	PW(0.787) GW(0.857) PL (0.857)	CNV(0.930) SW(0.942)	PHV (0.837) GL (0.869)	CL (0.945)

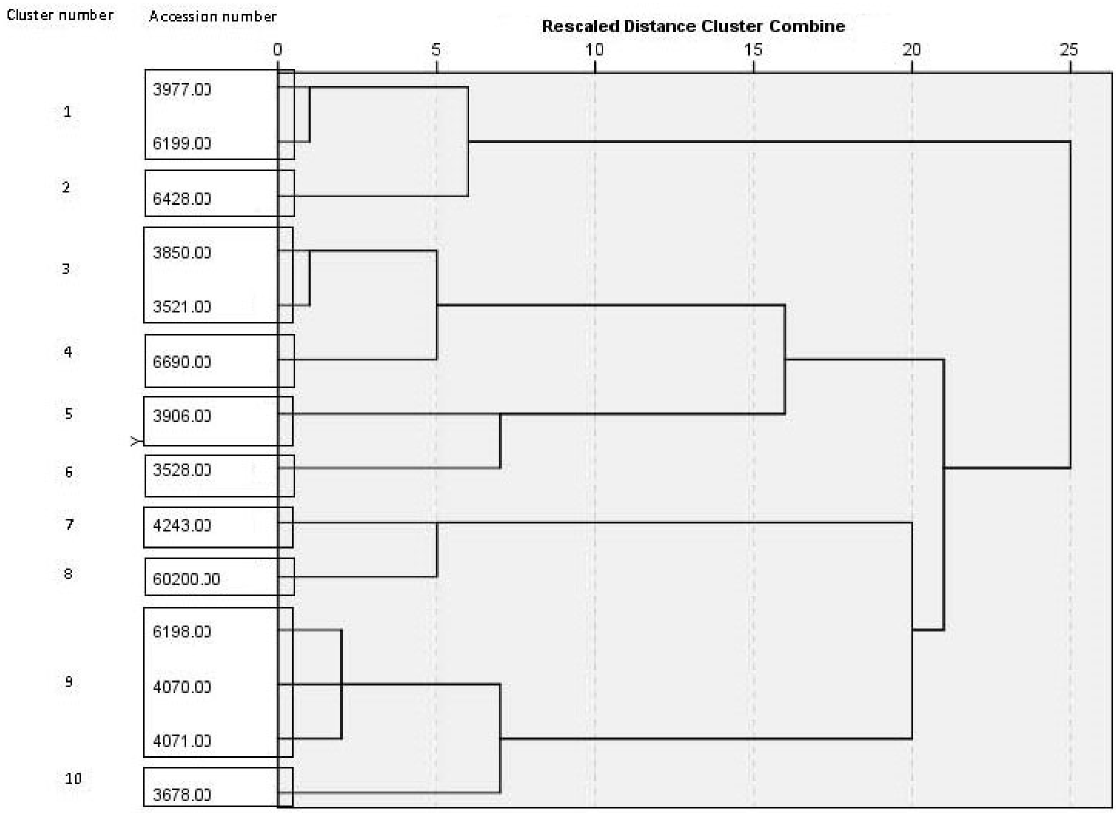

Figure 01: Dendogram of *Hondarawala* accessions derived through Ward's linkage method of Cluster Analysis based on 17 vegetative and yield characters.

Based on the cluster analysis, accessions with distinct flowering times and related morphological characters can be identified. Genes responsible for DF may associate with genes for morphological characters or DF genes are pleiotropic. In our attempt to identify the relationship between DF in Sri Lankan rice accessions of *Hondarawala* and morphological characters of vegetative and yield could be useful in future breeding programmes for yield increment.

CONCLUSION

DF and quantitative morphological characters of PH, CL, CN, CD, PL, GL, GW, LN, LL, LW, LiL, RL, SW, PW, PHV and CNV varied among 15 accessions.

Qualitative morphological characters of LA, FLA, LBP, LBC, LS, LiS, IC, CA, CS, PT, PE, PA, SB, AP, AC, ApC, LPC, LPP, PCC and SLC were varied among accessions. Vegetative morphological characters of PH, CL, LL, RL, SW, PHV, LN and CNV were positively correlated with DF while LW and PW (a yield component) were negatively correlated. First four Principal components (PA) explained 86.5% of total observed variation among accessions.

ACKNOWLEDGEMENTS

Authors acknowledge National Research Council, Sri Lanka for funding the research through NRC 12-129 grant, Plant Genetic Resources Center, Gannoruwa, Sri Lanka for rice seeds and Mr. K.G.P.B. Karunarathna of Rice Research and Development Institute, Bathalagoda, Sri Lanka for field establishment and assistance in data collection.

REFERENCES

Best K. (1961). Some aspects of photoperiodism in rice (*Oryza sativa L.*). *Elsevier,* Amsterdam. 87.

Chandraratna M. F. (1964). Rice plant physiology and photoperiod of rice. *Genetics and breeding of rice.* Longmans, London. 389.

Collinson S.T. Summerfield R.J. Ellis R.H. Roberts E.H. (1992). Durations of the photoperiod sensitive and the photoperiod insensitive phases of development to flowering in four cultivars of rice (*Oryza sativa L.*) *Annals of Batany* 70: 339-346.

Coolhaas C. and Wormer T.M. (1953). Developmental difference in rice plants in relation to photoperiodism. *Neth. J. Agric. Sci.* 1:202-216.

Doi K. Izawa T. Fuse T. Yamanouchi U. Kubo T. Shimatani Z. Yano M. and Yoshimura A. (2004). *Ehd1*, a *B-type* response regulator in rice, confers short-day promotion of flowering and controls *FT*-like gene expression independently of *Hd1*. *Genes Dev*. 18: 926-936.

Endo-Higashi N. and Izawa T. (2011). Flowering Time Genes *Heading date 1* and *Early heading date 1*, Together Control Panicle Development in Rice, *Plant Cell Physiol*. 52(6): 1083–1094.

Geekiyanage S. Madurangi S.A.P. and Rathnathunga E.U.U. (2012). Effect of photoperiod on flowering time and attributed traits of selected Sri Lankan rice varieties, *10th Academic sessions, University of Ruhuna*. 70.

Hu D. Smith E.R. Garruss A.S. Mohaghegh N. Varberg J.M. Lin C. Jackson J. Gao X. Saraf A. Florens L. Washburn M.P. Eissenberg J.C. Shilatifard A. (2013). The Little Elongation Complex Functions at Initiation and Elongation Phases of snRNA Gene Transcription. *Mol. Cell* 51(4): 493--505.

International Board for Plant Genetic Resources-International Rice Research Institute and Rice Advisory Committee. (1980). Descriptors For Rice *Oryza sativa l., International Rice Research Institute,* Los Baños, Laguna, Philippines.

International Rice Research Institute and Biotechnology International. (2007). Descriptors for wild and cultivated Rice (*Oryza spp.*) International Network for the Improvement of Banana and Plantain and International Plant Genetic Resources, *International Rice Research Institute*, Los Baños, Laguna, Philippines.

Izawa T. (2007) Adaptation of flowering time by natural and artificial selection in Arabidopsis and rice. *J Exp Bot.* 58:3091-3097.

Janardhan K.V. and Murty. K.S. (1967). Effect of photoperiod on panicle emergence in rice. *Curr. Sci.* 36:382-383.

Kojima Y. Ebana K. Fukuoka S. Nagamine T. and Kawase M. (2005). Development of an RFLP-based rice diversity research set of germplasm. *Breeding Science*. 55:431:440.

Komiya R. Yokoi S. and Shimamoto K. (2008). *Hd3a* and *RFT1* are essential for flowering in rice. *Development*. 136:3443-3450.

Lu J.J. and Chang T.T. (1980). Rice in its temporal and special perspectives. In: LuhBs (ed) Rice: production and utilization. *AVI publishing Coinc, Westport.* 1-74.

Matsuzaki, J., Kawahara, Y., and Izawa, T. (2015). Punctual Transcriptional Regulation by the Rice Circadian Clock under Fluctuating Field Conditions. *The Plant Cell*, *27*(3): 633-648.

Plant Genetic Resource Center, (2006). Characterization Catalogue on Rice (*Oryza sativa*) Germplasm, *Department of Agriculture.* Sri Lanka.

Rathnathunga E.U.U. Pushpakumari W.H.D.U. Padukkage P.D.C. Dissanayake, N. Fernando K. Rathnasiri, P.W. Senanayake, G. Senaweera, S. and Geekiyanage, S. (Team of NRC research project 12-129), (2014). Handbook on Varietal Diversity of Sri Lankan Traditional Rice (*Oryza sativa L.*), *University of Ruhuna*, Sri Lanka, ISBN: 978-955-0263-01-1.1: 82.

Rice Research and Development Institute, Sri Lanka, website DOASL, Rice Knowledge Bank, *International Rice Research Institute*, Retrieved on June 14, 2014, (http://www.knowledgebank,irri.org/SriLanka/padd-vari.html/) .

Roberts E.H. Summerfield R.J. (1987). Measurement and prediction of flowering in annual crops. In: Atherton JG, ed. *Manipulation of flowering.* London: Butterworths, 17–50.

Rutger J.N. and Mackill. D.J. (2001). Application of mendelian genetics in rice breeding. In: G.S. Khush, D.S. Brar, and B. Hardy, editors, Rice genetics IV. *International Rice Research Institute*, Los Baños, Philippines; Science Publishers, *Inc., Enfield,* NH.27–38.

Rutger J.N. and Tai. T.H. (2005). Registration of K/Z mapping population of rice. *Crop Sci*. 45:2671–2672. doi:10.2135/cropsci2005.0172

Song Y.L. Gao Z.C. and Luan W.J. (2012). Interaction between Temperature and Photoperiod in regulation of flowering time in rice, *Science China*, 55 (3): 241-249.

Tehrim, S., Pervaiz, Z. H., Mirza, M. Y., Rabbani, M. A., and Masood, M. S. (2012). Assessment of phenotypic variability in rice (*Oryza sativa L.*) cultivars using multivariate analysis. *Pak. J. Bot*, 44(3): 999-1006.

Vergara B.S. and Chang T.T. (1985). The Flowering Response of the Rice Plant to Photoperiod, A review of the literature, *International Rice Research Institute*. Los Baños, Laguna, Philippines.

Wei X. Xu J. Guo H. Jiang L. Chen S. Yu C. Zhou Z. Hu P. Zhai H. and Wan J. (2010). *DTH8* Suppresses Flowering in Rice, Influencing Plant Height and Yield Potential Simultaneously. *Plant Physiology*.153: 1747-1758.

Xue W. Xing Y. Weng X. Zhao Y. and Tang W. (2008) Natural variation in *Ghd7* is an important regulator of heading date and yield potential in rice. *Nat Genet*. 40:761-767

Yano M. Kojima S. Takahashi Y. Lin H.X. and Sasaki T. (2001) Genetic control of flowering time in rice, a short day plant. *Plant Physiol*. 127:1425-1429

Yano M. and Izawa T. (2005). Genetic and molecular dissection of flowering time in rice, Rice Genetics V, Proceedings of the Fifth International Rice Genetics Symposium, *International Rice Research Institute*. Los Baños, Laguna, Philippines. 355.

Yoshimura A. N. Takano-Kai T. Eguchi M. Ashikari O. Ideta K. Doi and H. Yasui. (2001). RFLP mapping of 95 morphological trait loci in rice. *Breed Res.* 3 (Suppl. 1):94.

Yu, Z.H., S.R. Mc Couch, T. Kinoshita, S. Sato, and S.D. Tanksley. (1995). Association of morphological and RFLP markers in rice (*Oryza sativa L.*). *Genome* 38:566–574. doi:10.1139/g95-073.