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PHOTOPERIOD DRIVEN DAYS TO FLOWERING VARIATION AFFECT VEGETATIVE GROWTH AND YIELD IN SRI LANKAN TRADITIONAL RICE (*ORYZA SATIVA* L) *MA WEE*

W.H.D.U. PUSHPAKUMARI[1], GAMINI SENANAYAKE[2], SUDARSHANEE GEEKIYANAGE[2]

[1]*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*
Corresponding author's email: sudarshanee@agbio.ruh.ac.lk

Abstract

Variation in days to flowering (DF) is evident in Sri Lankan traditional rice (SLTR) with short aged and long aged varieties while short day sensitive extremes do not flower during non inductive season. *Ma wee* varieties of SLTR are known for photoperiod sensitivity while being candidates for adaptability to adverse environments. Effect of two photoperiod regimes during *Maha* growing season {late *Maha* (LM) of more long days in 2013/2014 and early *Maha* (EM) of more short days in 2014/2015} on vegetative growth parameters, DF and yield components were determined in 43 *Ma wee* accessions (close to the number of total collection at gene bank) under Sri Lankan field condition. Only 9 accessions flowered out of 43 accessions during experimental period of ten months in LM. DF was variable within season among above accessions as 71 ± 5.3 to 164 ± 2.1 in LM and 51 ± 0.4 to 166 ± 6 in EM. Except for accession 3598 DF of above accessions were lower in EM in contrast to that in LM. Plant height (PH), DF and grains per panicle (GPP) were significantly affected by season, accession and interaction of accession and season. Total tiller number (TTN) was mainly affected by accession and interaction of accession and season. Yield components of total panicle weight (TPW), grains per panicle (GPP) and first panicle weight (FPW) were increased by increasing DF in EM as TPW= 117.5 +3.465 DF -0.01398 DF^2, GPP = 78.36 + 1.478 DF, and FPW = 1.364 +0.03031DF while, hundred grain weight (HGW) was decreased as HGW = 3.724 - 0.01160 DF. Our results on relationships between DF and yield and, DF and vegetative growth in *Ma wee* at 2 photoperiodic seasons as the first report for *Ma wee* according to the best of our knowledge would be useful in manipulating DF for better yields in breeding programmes.

Key words: Days to flowering, Photoperiod regimes, Sri Lankan traditional rice *Ma wee*, Vegetative growth, Yield.

Introduction

Increasing rice yield would be an important objective in achieving global food security. Rice yield is mainly controlled by the genotype, climate, soil environment, and management practices (Richards, 2000). Yield and plant structure can be affected by flowering time in rice (Itoh *et al*, 2010; Xu *et al*., 2014). Rice, being a facultative short day plant, responds to short days for flower initiation (Yano *et al*., 2001; Hayama & Coupland, 2004). Flowering time is also important in ecological adaptation in rice as it determines the crop duration (Andres & Coupland, 2012). Therefore, photoperiod sensitivity for flower initiation is a critical agronomic trait in developing rice for different agro-ecological regions (Izawa, 2007). Pleiotrophic effects of photoperiod pathway genes for flowering time *SE13*, *Hd1* and *GHd7* had been revealed by Xu *et al*. (2014): The photoperiod insensitive alleles of *se13, hd1* and *ghd7* had affected yield components promoting early flowering and reduced biomass accumulation. Individual effects of flowering time genes on yield components were reported to be different to each other: The *se13* plants produced a fewer panicles. The *hd1* plants showed poor grain filling percentage, while *Ghd7* affected number of grains per panicle and fewer secondary branches (Xu *et al*., 2014). The combined effect of *Hd 1* and *EHd 1* genes regulate the panicle development and plant architecture. (Endo Higashi & Izawa, 2012). Flowering time, yield and plant height regulated by *DTH8* as well (Wei *et al*., 2010).

Rice is the major food crop in Sri Lanka. New improved rice varieties had been introduced to Sri Lanka from IRRI in 1960s to overcome photoperiod sensitivity and large plant architecture in Sri Lankan traditional rice (Rajapaksha *et al*., 2011). New improved varieties have already reached the maximum yield potential (Department of Census and Statistics, 2015). Sri Lankan traditional rice germplasm consists of morphologically variable accessions collected from different agro ecological regions of the island and flowering time is variable among them as well (Rathnathunga *et al*., 2016). According to morphological characterization of more than 700 accessions of Sri Lankan traditional rice collection, a wide variation in flowering time, plant architecture and yield components have been recorded (Team of NRC 12-129, 2014 & Team of NRC 12-129, 2015). Geographic location of the island Sri Lanka in tropics with variable agro-ecology might have led the development of above wider morphological and flowering time variation for ecological adaptation suggesting the potential resourceful genetic factors.

Ma wee was a major commonly grown traditional rice before the introduction of new improved rice for higher yields in 1960s in Sri Lanka. *Ma wee* accessions withstand extreme weather conditions (Wickramasinghe & Noda, 2008). *Ma wee* is a known photosensitive variety for flower initiation (Nawarathne *et al*., 2014). Farmers also claim that cultivation of *Ma wee* needs a very little labor. Although Sri Lanka locates in the tropics, there are two growing seasons with different day lengths: In *Yala* season, a long day photoperiod is experienced with gradual reduction of day length at the end of season while *Maha* season starts with short days and ends towards day neutral days. *Ma wee* possesses a long photoperiod insensitive basic vegetative period; Hence *Ma wee* cultivation is initiated just after the long day season as day neutral period is experienced for vegetative growth during this period (Personal communication with Dr MP Dhanapala, a former director of Rice Research and Development Institute, Sri Lanka). Growing season is critical for *Ma wee* flowering and *Ma wee* is only cultivated during *Maha* season to ensure that short days are received for flowering initiation. *Ma wee* could be an important genetic resource for future era of climate change due to the variation in flowering time based on ecology and claims on environmental stress tolerance. Therefore, seasonal sensitivity on morphological and flowering time variation, and the relationship between flowering time and yield were investigated in this study for utilization of *Ma wee* genetic factors in future breeding programmes.

Materials and Methods

Planting materials: Forty three *Ma wee* accessions (close to the total number of *Ma wee* accessions of gene bank) from Plant Genetic Resource Center (PGRC), Sri Lanka were used for the experiment (Table 1).

Table 1. *Ma wee* varieties and accessions used for the study.

Variety name	Accession number
Ma wee	4681, 4135, 8497, 4766, 6710, 4136, 5384, 3704, 8551, 3618, 8552, 3683, 6699, 4666
Sudu Ma wee	3711
Ma wee Samba	4561
Maha Ma wee	3551, 3600, 8543, 4301, 4125, 8696, 4134, 8542, 3599, 4559, 8541
Bala Ma wee	3598, 6149
Heen Horana Ma wee	3608
Horana Ma wee	3625, 3649
Kuru Ma wee	3640, 3682, 4760, 4113, 6253, 4290
Kuru Ma wee Samba	4435
Sudu Kuru Ma wee	3933
Nandu Ma Wee	4778

Table 2. Meteorological data of the experimental field.

Year	Month	Average temperature (ºC)	Average rainfall (mm)	Day length (hours)
2013	December	29.3	53.9	11.46
2014	January	28.6	129.3	11.48
2014	February	29.6	58.1	11.56
2014	March	31	48.4	12.05
2014	April	31.3	90.2	12.15
2014	May	30	233.7	12.23
2014	June	29.6	298	12.27
2014	July	29.5	90.6	12.25
2014	August	28.6	218.6	12.17
2014	September	29.1	249.8	12.08
2014	October	28.5	463.9	11.58
2014	November	28.3	222.6	11.50
2014	December	29	249.7	11.46
2015	January	29	43.8	11.48
2015	February	28.7	219.6	11.55
2015	March	30.1	50.7	12.05
2015	April	30.5	311.6	12.15
2015	May	30	204.5	12.23

Source: Meteorological unit, Department of Agricultural Engineering, Faculty of Agriculture, University of Ruhuna, Sri Lanka

Field experiment: The experiment was conducted during late *Maha* (LM) (December 2103 to September 2014) and Early *Maha* (October to May 2015) seasons at the field of Faculty of Agriculture, University of Ruhuna in Kamburupitiya, Sri Lanka (at 6° 17' 0" of North and 81° 17' 0" of East). Meteorological data of the experimental field was recorded (Table 2). Seeds were germinated in nursery pots and two weeks old seedlings were transplanted in the spacing of 40 cm x 40 cm as inter and intra row in a Completely Randomized Design (CRD) with four replicates in an apparently uniform paddy field.

Basal and top dressing fertilizers were applied at the time of field planting and at tillering according recommendation of the Department of Agriculture, Sri Lanka for the agro-ecological zone. Manual weeding was done at regular intervals and competition from weeds was kept minimal.

Data collection: Days to flowering (DF) was recorded as number of day count from effective seeding date to first flowering date of the first panicle of the main culm), Plant height (PH) were measured in cm from ground level to the tip of the top leaf at late vegetative stage. Total tillers number (TTN) was measured at the late vegetative stage. Grains per panicle (GPP), Total Panicle weight (TPW), Hundred grain weight (HGW) and First Panicle weight (FPW) were recorded according to the descriptor developed by team of NRC 12-129 (2014).

Statistical analysis: Two factors (season and accession) were tested using the experimental design of CRD: The factor "season" consisted of two levels as EM and LM, while factor "accession" composed of 43 levels. The main effects and interaction effects were checked through two way ANOVA. Regression and correlation analysis were carried out. Mean separation was performed by Turkey's test. All analysis was carried out with Minitab 15 version (USA).

Results

Seasonal sensitivity on days to flowering: Only nine accessions flowered and the rest 34 accessions of the collection did not flower during the experimental period of ten months. The flowered accessions belonged to the varieties of *Ma wee* (accessions 5384, 3704 and 4666), *Bala Ma wee* (3598 and 6149), *Heen Horana Ma wee* (*3608*), *Horana Ma wee* (3625 and 3649) and *Kuru Ma wee Samba* (4435). DF varied among above accessions during two seasons from 71 ± 5.34 (CV % =4.1) to 164 ± 2.12 (CV % =2.7) days during LM and from 52 ± 1.5 (CV % = 7.26) to 106 ± 0.44 (CV % = 0.55) during EM (Fig. 1). The significantly different minimum and maximum DF were observed in accessions 4435 and 3704 respectively (Table 3). There was a seasonal effect on DF as nine accessions of above, flowered significantly early under EM over LM with wide variations, while DF of accession 3598 was not affected by season. (Fig. 2 (a) and 2 (b) and Table 3). In EM, DF varied from 51 ±0.4 (CV % =1.44) in 3786 to 166 ± 0.6 (CV %= 7.26) in accession 8541, where all accessions flowered during experimental period. Average DF for all accessions during LM was 112 ±11.2, (CV % = 29.88) over 78.78 ±5.26 (CV%= 20.03) of that during EM for the 9 accessions (Table 4).

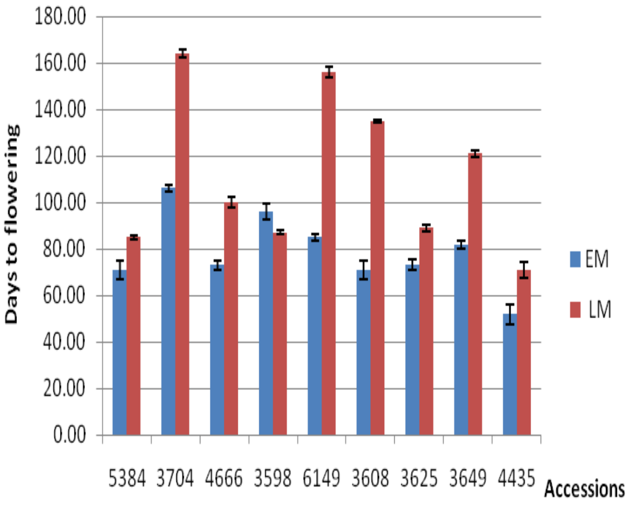

Fig. 1. Effect of seasonal sensitivity on days to flowering among 9 mild sensitive accessions during two seasons.

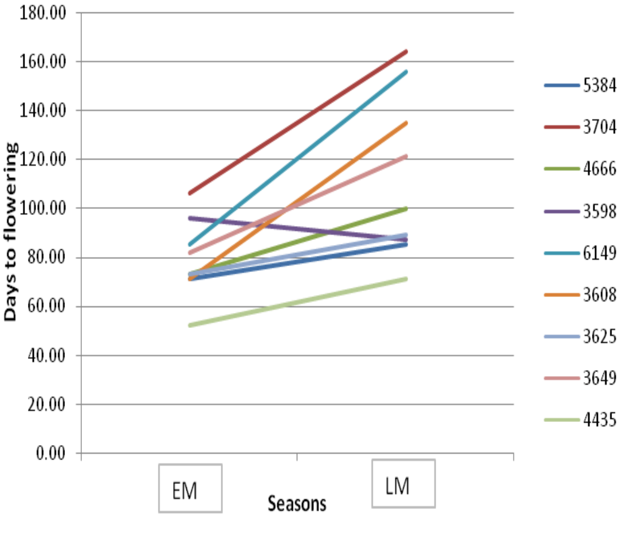

Fig. 2 (a). Interaction of season and accession on days to flowering in mild sensitive accessions.

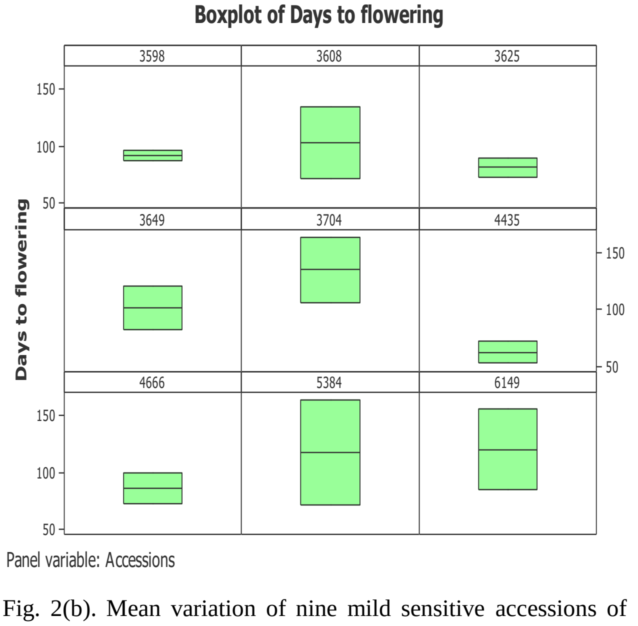

Fig. 2(b). Mean variation of nine mild sensitive accessions of *Ma wee* in two growing seasons.

Table 3. Within and between season variation in days to flowering among 9 mild sensitive accessions.

Accession	EM	LM	P value
5384	71.00 ± 2.40	85 ± 1.2	0.04*
3704	106.00 ± 2.30	164 ± 3.75	0.00*
4666	73.00 ± 0.06	100 ± 4.9	0.01*
3598	96.00 ± 6.10	87 ± 1.6	0.23
6149	85.00 ± 2.60	156 ± 0.8	0.00*
3608	71.00 ± 0.80	135 ± 6.17	0.00*
3625	73.00 ± 0.60	89 ± 6.98	0.07
3649	82.00 ± 0.80	121 ± 12.73	0.03*
4435	52.00 ± 1.70	71 ±1.73	0.00*

* Indicates that values are significant at p<0.05

Effect of season, accession and interaction on DF was revealed to be significant (Table 5).Varieties of *Ma wee* (5384, 3704 and 4666), *Bala Ma wee* (3598 and 6149), *Heen Horana Ma wee (3608)*, *Horana Ma wee* (3625 and 3649) and *Kuru Ma wee Samba* (4435) were affected by season and accession (Table 3), where there was a significant interaction between accession and season as well (p<0.05) (Fig. 2).

Seasonal sensitivity on plant height at vegetative stage: Average PH during LM was 155.8 ± 3.63 (CV % =15.44), while that of EM was 104.2 cm ± 2.06 (CV % = 13.1) (Table 4).

During LM, plant height at vegetative stage varied from 72 cm ± 0.76 (CV %= 2.41) to 199 cm ±1.65 (CV %= 4.11). Significantly different minimum and maximum PH were recorded from accessions 5384 and 3704. In EM season, PH varied from 80 cm ± 2.2 (CV %= 13.4) in accession 4760 to 139 cm ± 1.9 (CV % = 8.03) in accession 3625 (Fig. 3).

Except for accession 5384 of *Ma wee*, accession 6253 of variety *Kuru Ma wee* and 4134 of *Maha Ma wee*, all accessions produced significantly higher PH under LM (Fig. 4). PH was determined by accession, season and interaction between accession and season (Table 5).

The equality of population means was tested using two way normal ANNOM. The graph displays each factor level mean, the overall mean, and the decision limits. The points of falls outside the decision limits are significantly different from the overall mean. The interaction between season and accession was evident as accessions of 4125, 4134 and 3551 (*Maha Ma wee)* and 3625 (*Horana Ma wee)* were significantly affected by season (Fig. 5).

Seasonal sensitivity on total tiller number at vegetative stage: Total tiller number at late vegetative stage varied from 2 ± 5.4 (CV % = 60.34) of accession 6253 to 22±4.1 (CV % =3.08) of accessions 4135 and 6710 in LM season. In EM season, TTN varied from 4 ± 1.15 (CV % =39.85) of accession 6702 to 29± 3.1 (CV % =35.98) of accession 3598. Average TTN of LM and EM were 13 ± 0.711 (CV % = 36.27) and 11.15± 0.601 (CV % = 35.74) respectively (Table 4). TTN was significantly different among accessions and between seasons (Table 5).

The variation of TTN is affected mainly by variety (Fig. 6) as well as by interaction effect of season and variety (Fig. 7).

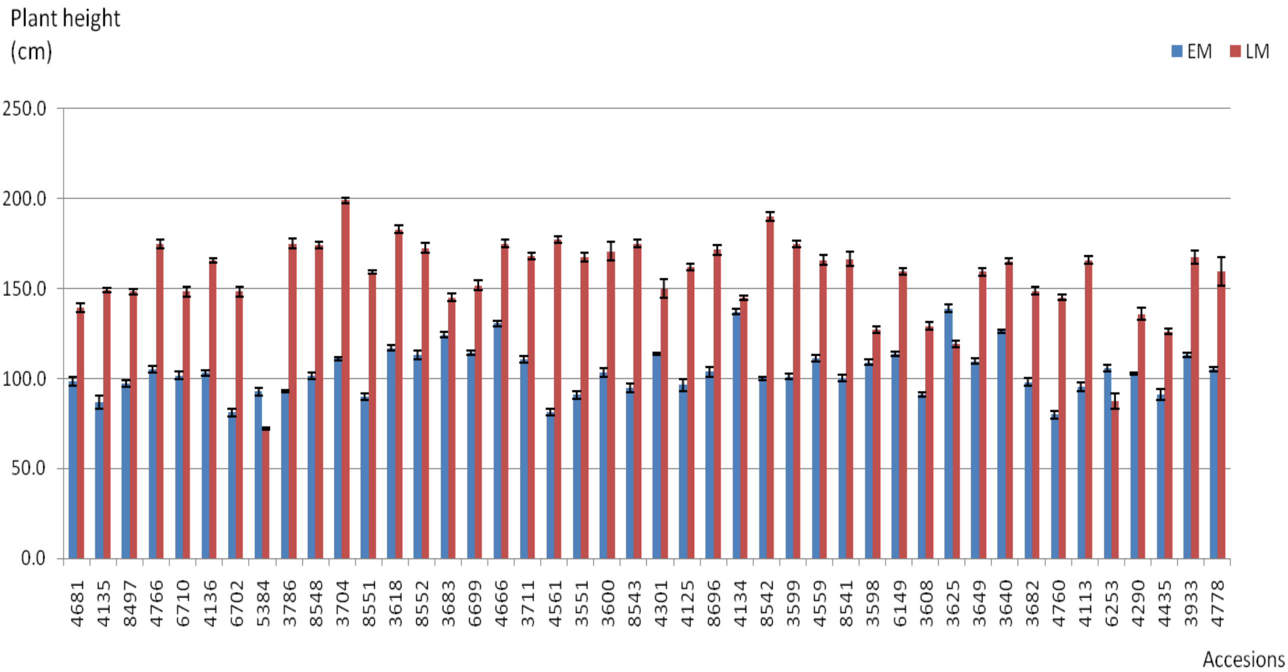

Fig. 3. Plant height variations among 43 *Ma wee* accessions during two seasons.

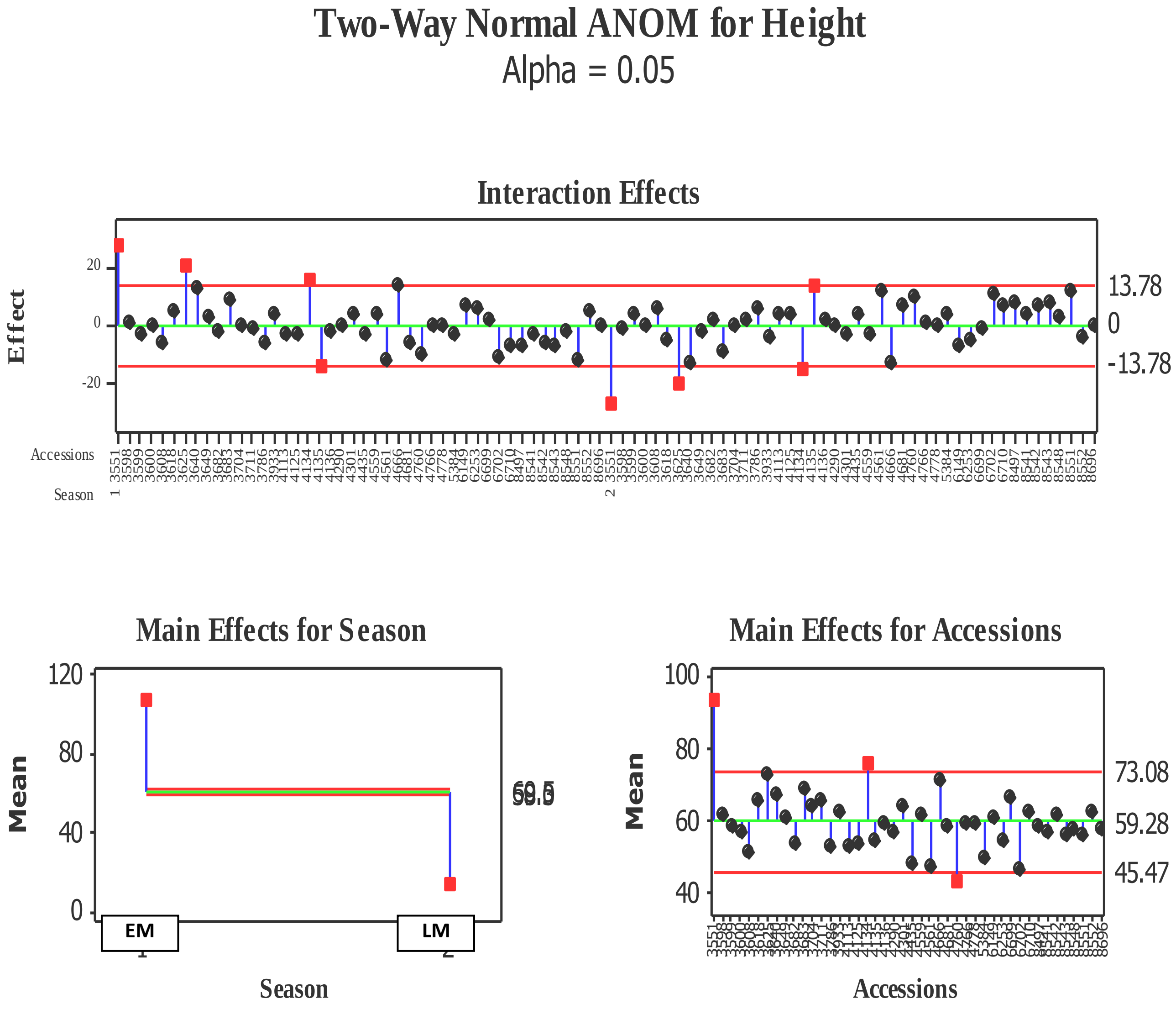

Fig. 5. Analysis of means of plant height.

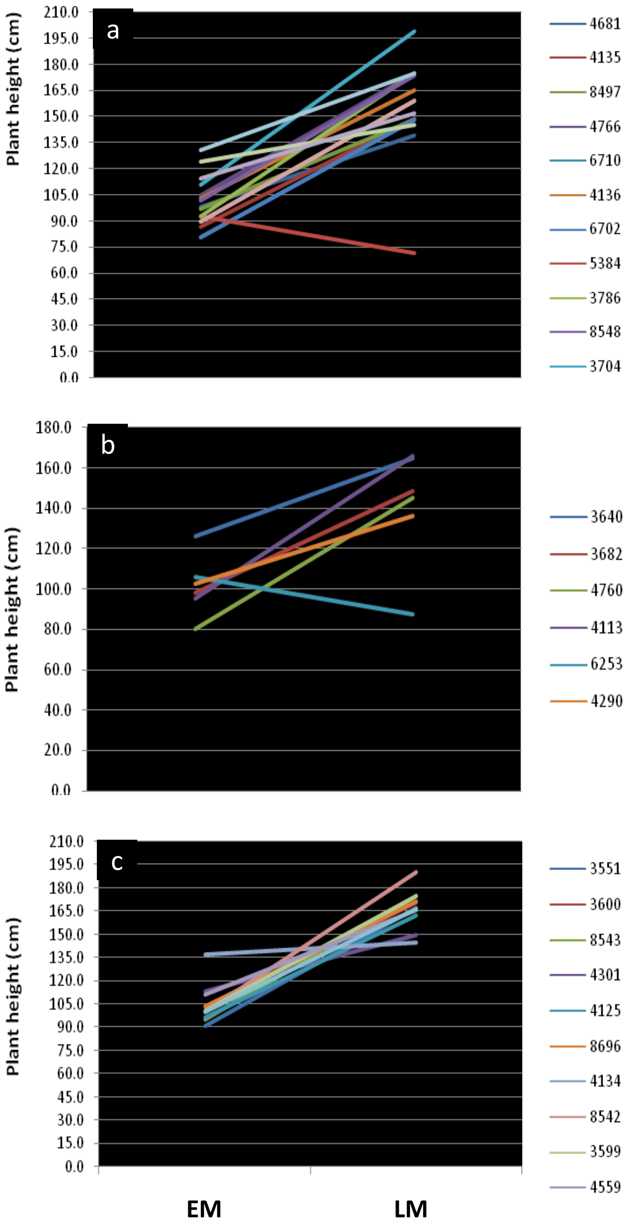

Fig. 4. Interaction between accession and season on plant height among accessions of 3 *Ma wee* varieties.
(a) *Ma wee* (b) *Ku Ma wee* (c) *Maha Ma wee*

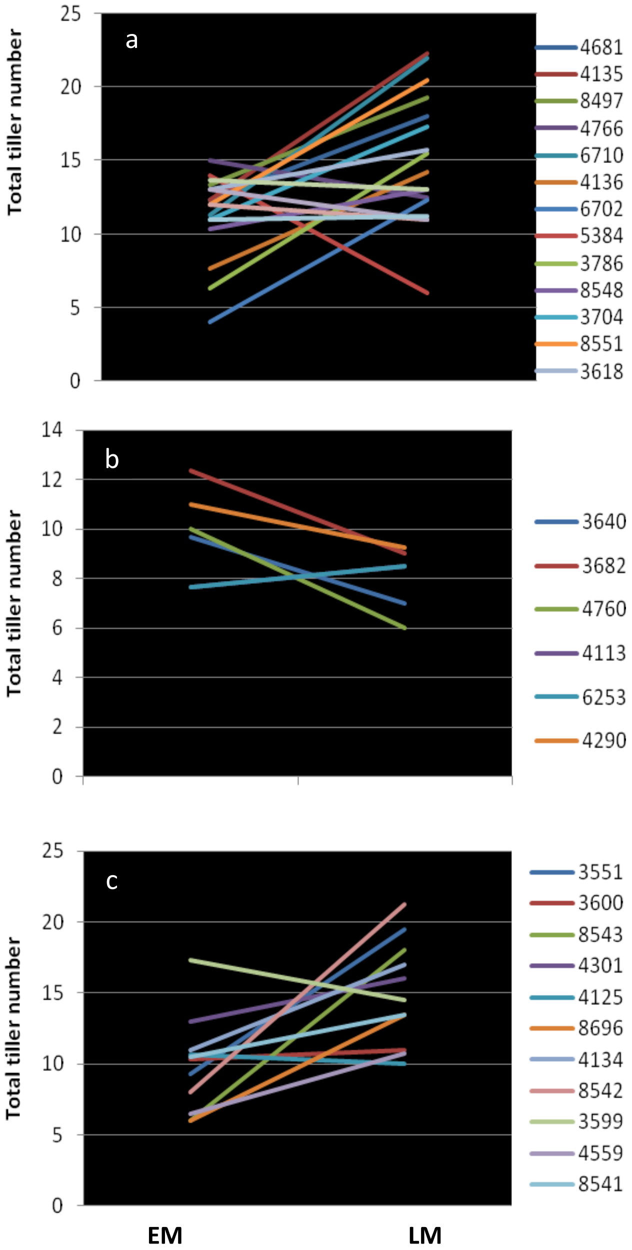

Fig. 7. Interaction between accession and season on total tiller number in accessions of 3 *Ma wee* varieties.
(a) *Ma wee* (b) *Ku Ma wee* (c) *Maha Ma wee*

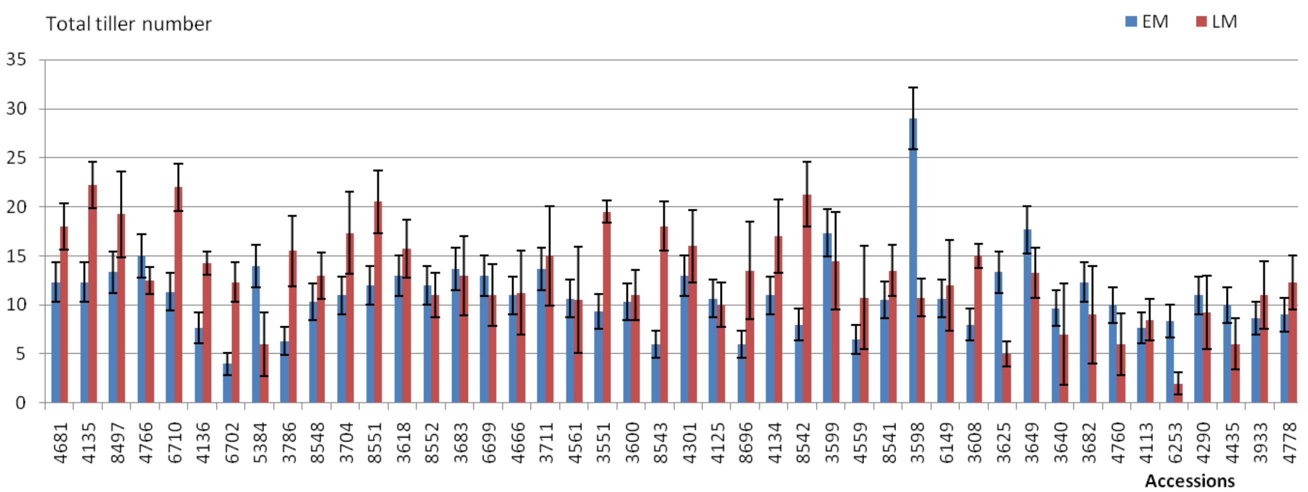

Fig. 6. Variation of total tiller number of accessions during two seasons.

Table 4. Descriptive statistics of variables during two seasons.

Season	Variable	Mean	SE mean	SD	Variance	CV	Sum	Min.	Max.	Range
EM	PH	104.2	2.06	13.65	186.37	13.1	4584.6	80	139	59
	TTN	11.15	0.601	3.98	15.88	35.74	490.66	4	29	25
	DF	78.78	5.26	15.78	248.94	20.03	709	52	106	54
	GPP	183.1	19.3	57.8	3340.3	31.56	16.483	75	248	173
LM	PH	155.8	3.63	24.07	579.46	15.44	6858.2	72	199	127
	TTN	13.00	0.711	4.718	22.259	36.27	572.41	2	22.3	20.25
	DF	112	11.2	33.5	1119.8	29.88	1008	71	164	93
	GPP	74	6.84	20.51	420.5	27.71	666	32	101	69

Table 5. Analysis of variance (mean squares) for agronomic traits.

Source of variance	TTN	PH	DF	GPP
Season	77.45	575400*	14569.8*	160067*
Accession	78.5*	452*	2970.2*	5955*
Season* Accession	47.38*	458*	1118.5*	5315*

* Indicates significant differences at the 0.001 probability level

Table 6. Determination of relationships of DF with yield components.

Yield determinants	Regression model	R^2value
TPW	117.5 +3.465 DF -0.01398 DF^2	67.7
HGW	3.724 - 0.01160 DF	55.3
GPP	78.36 + 1.478 DF	68.7
FPW	1.364 +0.03031DF	45.6

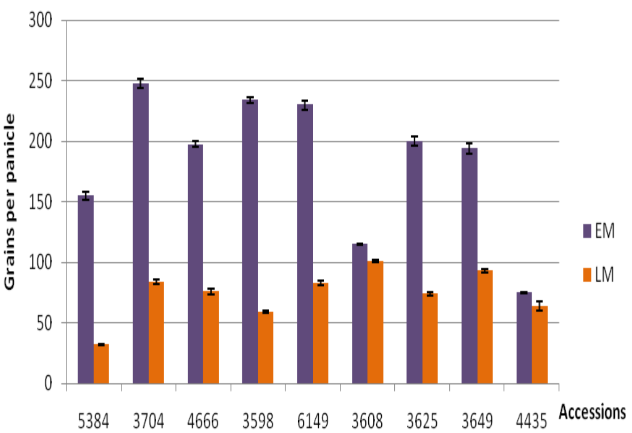

Fig. 9. Variation in grains per panicle of 9 mild sensitive accessions during two growing seasons.

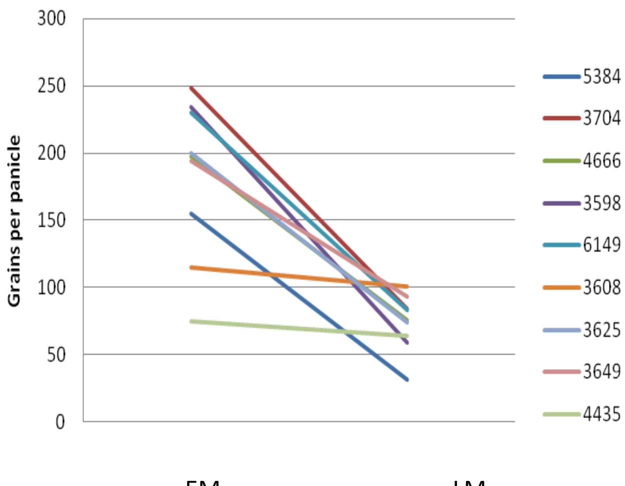

Fig. 10. Interaction effect on grains per panicle.

According to Fig. 8, the accessions 3551, 3598 and 6253 were significantly different from other accessions for total tillers number. TTN of the accession 3598 was significantly different from that of others in a given season.

Seasonal sensitivity on grains per panicle: The GPP varied from 32 ± 0.7 in accession 5384 to 101 ± 0.6 in accession 3608 in LM season, where it was from 75 ± 0.4 in accession 4435 to 248 ± 3.7 in accession 3704 in EM season. The GPP was affected by accession, season (Fig. 9) and interaction between accession and season as evident in accessions 3598, 3608 and 4435 (Figs. 10 and 11 and Table 5).

Determination of relationship between vegetative growth and yield with days to flowering: The variation of GPP in EM season was from (accession 4435) 75 ±0.44 to 248 ± 3.74 (accession 3704), while it ranged from 32 ± 0.71 (accession 5384) to 101 ±0.57 (accession 3608) during LM season. The relationship between DF and GPP in LM season was GPP = 0.402DF +28.95, while GPP = 3.230 DF -71.32 in EM season respectively. The effect of DF variation on GPP was evident. The relationship between DF and TTN was as follows, TTN = 0.206 DF -2.11 in EM season and TTN = 0.107DF -1.356 in LM season. The relationship between DF and PH also varied between two seasons. PH in EM was = 0.269 DF+ 88.53 while LM was PH= 0.741DF 57.61 (Fig. 12).

Effect of DF on total panicle weight: Total panicle weight varied from 13.33g ± 1.48 (CV% = 49.60) in accession 4301 to 144.88g ± 0.71 (CV% =1.04) in accession 4135 in EM season. Regression model developed for the correlation was significant at $p<0.05$ level (Table 6). The effect of DF on TPW was as TPW= 117.5 +3.465 DF -0.01398 DF^2, where R^2 was at 63.09 % (Fig. 13a).

Effect of DF on hundred grain weight: Hundred grain weight varied from 1.51g ± 0.14 (CV% = 3.98) of Accession 4301 to 3.39 g ± 0.23 (CV % = 4.58) of Accession 3786 during EM season. The regression was negatively linear as HGW = 3.724 - 0.01160 DF, where R^2 was at 50.2% (Fig. 13b).

Effect of DF on grains per panicle: Grains per Panicle varied from 75 ± 0.44 (CV% = 15.22) of Accession 4435 to 442 ± 0.82 (CV % = 16.12) of Accession 4561 during EM season. The regression relationship between DF and GPP was positively linear: GPP = 78.36 + 1.478 DF, where R^2 was at 62.3% while that during inductive photoperiod season was GPP= 402 DF+2895 (Fig. 13c).

Effect of DF on first panicle weight: First Panicle weight varied from 2.06g ± 0.43 (CV% = 26.52) of Accessions 5384 to 8.60g ± 0.44 (CV % = 6.98) Accessions 8551 during EM season. The regression relationship was positively linear as FPW = 1.364 +0.03031DF, where R^2 was at 37.0 % (Fig. 13d).

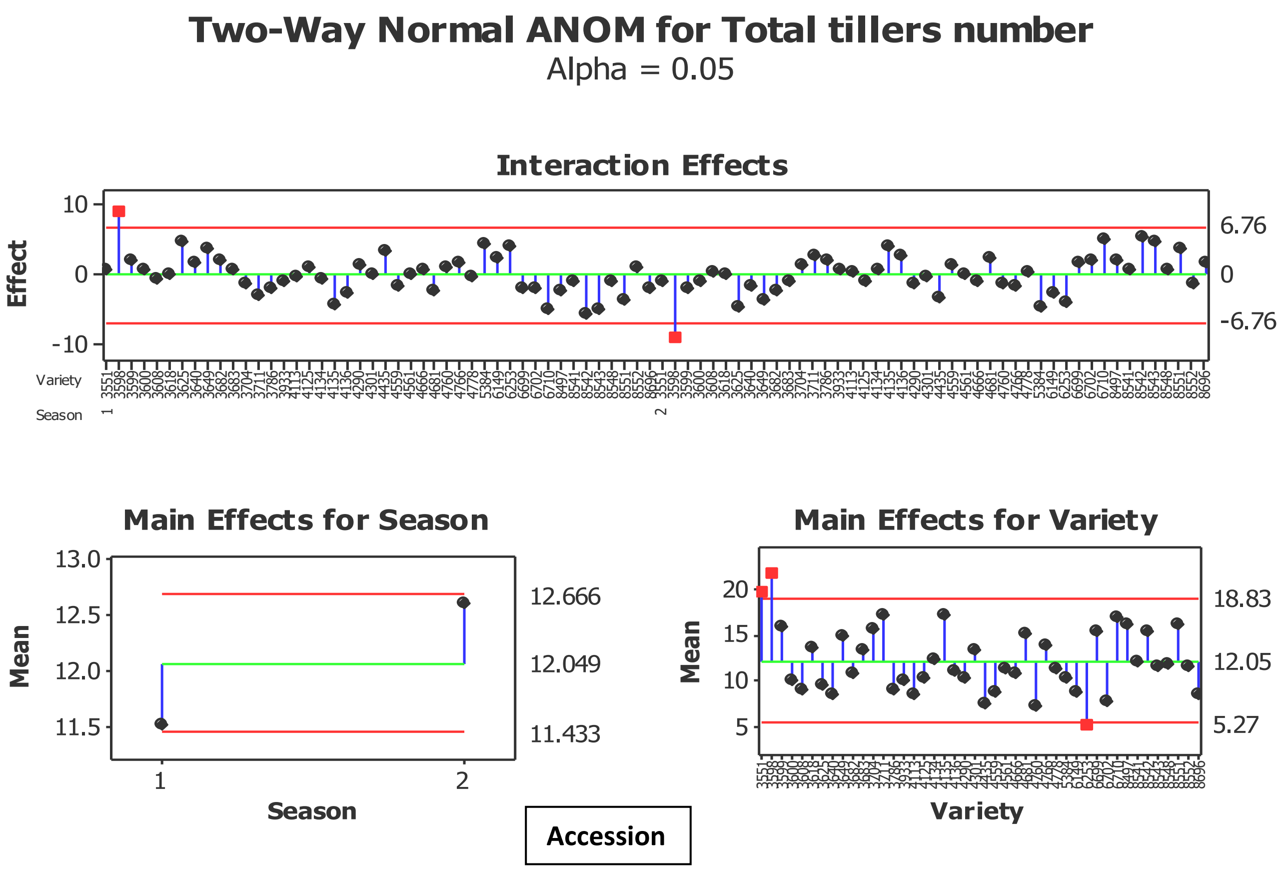

Fig. 8. Analyses of Means of Total Tiller Number during two seasons.

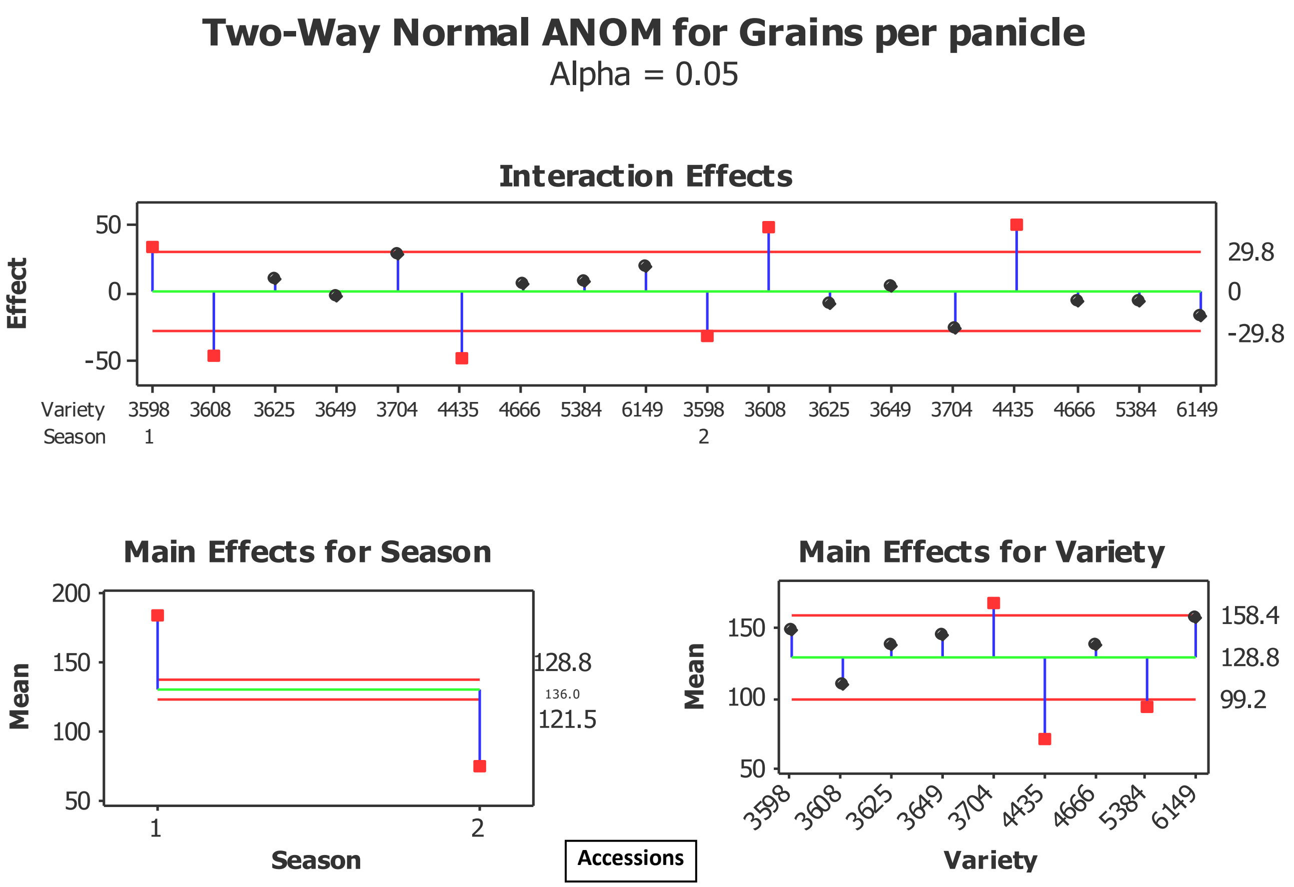

Fig. 11. Analyses of means of grains per panicle.

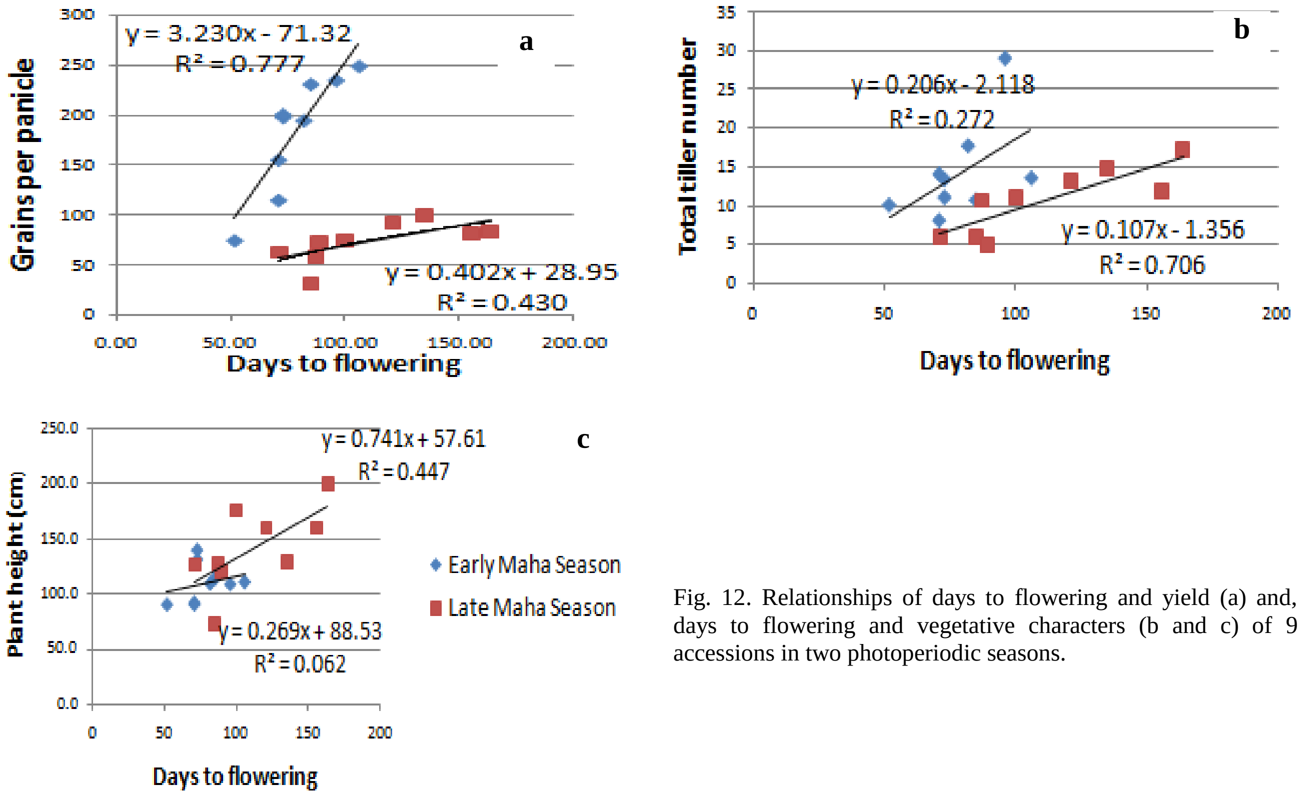

Fig. 12. Relationships of days to flowering and yield (a) and, days to flowering and vegetative characters (b and c) of 9 accessions in two photoperiodic seasons.

Relationship between days to flowering with yield components

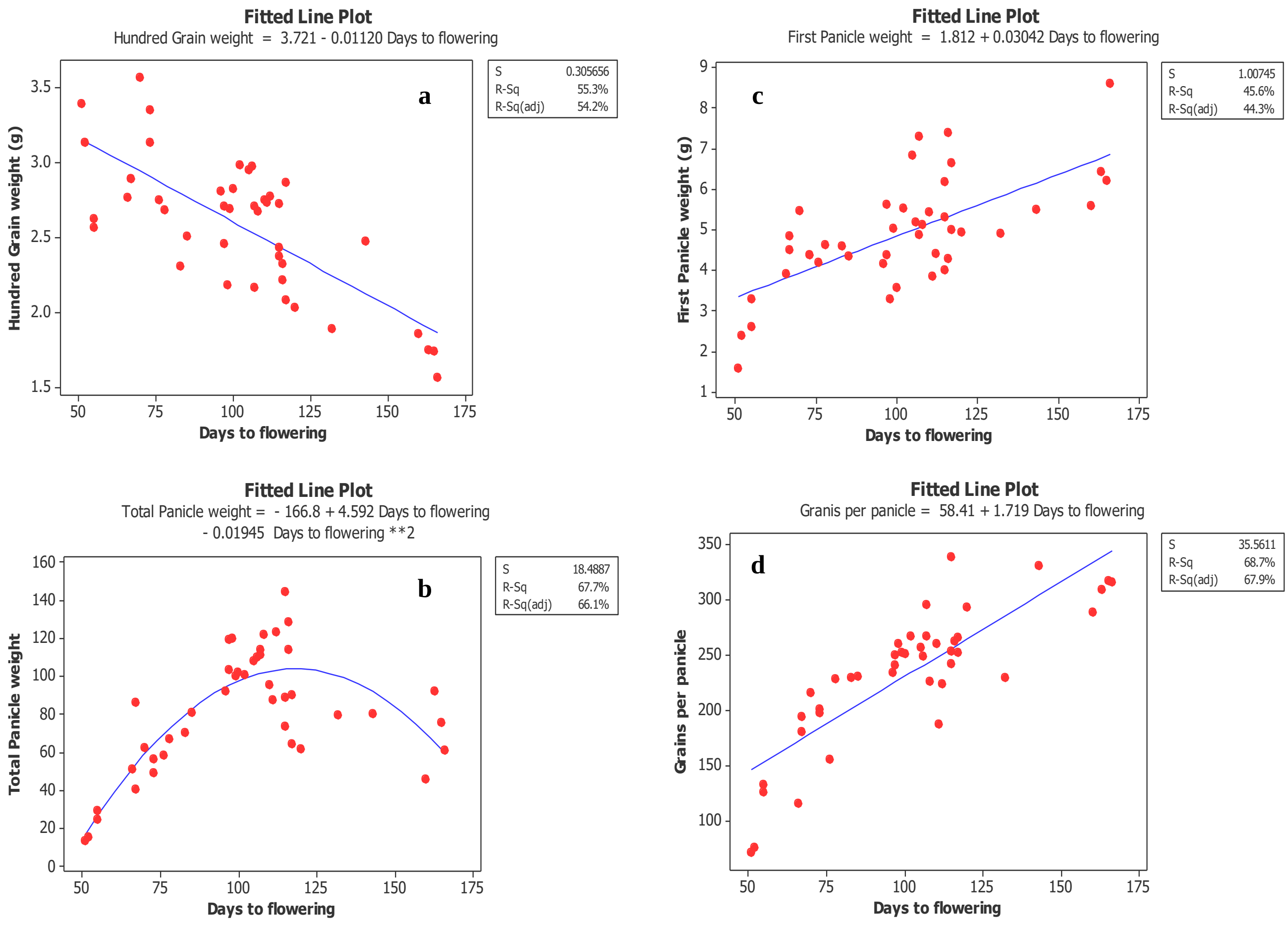

Fig. 13. Relationship between days to flowering and yield components of 43 accessions in early *Maha* season.
**a-DF and TPW, b-DF and HGW, c- DF and GPP, d- DF and FPW

Discussion

Results revealed that vegetative growth and days to flowering of accessions were affected by seasonal sensitivity. Vergara & Chang (1985) indicated that almost all *Oryza sativa indica* rice accessions mature in a shorter time under a short photoperiod than under long day photoperiod, where the degree of sensitivity varies greatly among accessions. According to Collinson *et al*. (1992) photoperiod sensitive inductive phase increased under LD. Only 9 accessions flowered during LM season, where more day neutral condition prevailed and, flowering of all accessions during more short day season (EM) proved the fact that there is a genetic variation on photoperiodic response to flowering among *Ma wee* accessions. Rathnathunga & Geekiyanage (2017) reported the differential response of *Ma wee* accessions 6702, 6699 and 3683 to photoperiod on plant height at early vegetative phase. In the present experiment, above 3 accessions were sensitive to LM season remaining in vegetative phase confirming the effect of photoperiod on different genotypes of Sri Lankan *Ma wee* accessions for vegetative growth and flowering initiation.

All accessions except for accession 3598 had higher DF and TTN in LM in contrast to those of EM. Accession 3598 had different responses to photoperiodic season unlike other accessions as TTN in LM (11 ± 4.9) was significantly lower than (29 ± 3.1) in EM (Fig. 7). The gene "grain number, plant height, and heading date 7" (*Ghd7*) was reported to be affecting the number of grains per panicle (Xu *et al*., 2014). Genetic factors responsible for flowering must be different from accession 3598 suggesting the presence of *ghd7* mutant alleles. GPP in 3598 during EM (DF= 87 ± 3.45 days) was 234 ± 2.50 while that in LM was 59 ± 0.88 (DF=96 ± 1.33days). *Ghd7* expression results in effects on DF, plant height and grain yield of rice under different photoperiod conditions (Gao *et al*., 2014). Okada *et al*. (2017) reported on synthetic control of rice flowering time by inducible *Hd3a* through agrochemicals in the non flowering background of *Ghd7* over expressing rice for insensitivity to environmental stimuli. Therefore, our report of non-flowering 34 *Ma wee* accessions under LM suggests the possession of *Ghd7* in them where Hd3a is not induced due to more long days under LM.

Mild photoperiod sensitive accessions, which flowered during LM indicated that increasing DF affects grain yield through increased grains per panicle and TTN (Fig. 12). The similar increasing trend was more acute under EM. Panicle size was significantly affected by days to flowering. According to the Endo-Higashi & Izawa (2012), ambient environmental conditions may partially control sink size through the action of the flowering time genes.

Genes responsible for early flowering must be responsible for above increased yield components, which must be identified for future breeding programmes.

The total accumulation of photosynthates is also an important factor controlling yields. The combinations of photosynthate accumulation and flowering time control may interact in complex ways to determine the total sink size of a plant: Shi *et al*. (2013) had described the source-sink dynamics under elevated night temperature and adverse effect on rice yield.

Above results confirm that PH was positively affected by DF (Fig. 12). Genes responsible for days to flowering are reported to be affecting PH (Yu *et al*., 2002 and Gao *et al*., 2014). Effect of photoperiodic season on PH was different only in accession 5384 in which PH was significantly higher in more short day season (EM) compared to more long day season (LM) where DF was less than that of EM.

Conclusions

There was a significant effect of accession on days to flowering within each season of more long days (LM) and more short days (EM), and between two seasons.

There were thirtyfour extremely short days sensitive accessions of *Ma wee* varieties, which did not flower during LM season. Varieties of *Ma wee* (accessions 5384, 3704 and 4666), *Bala Ma wee* (3598, 6149), *Heen Horana Ma wee* (*3608*), *Horana Ma wee* (3625 and 3649) and *Kuru Ma wee Samba* (4435) only flowered during the season with more long days (LM), which were named as mild sensitive accessions.

Regression models indicated that days to flowering positively affected total panicle weight, first panicle weight and grains per panicle while the hundred grain weight was negatively affected during EM in 43 accessions.

The regression model for days to flowering and grains per panicle for 9 mild sensitive accessions of *Ma wee* (accessions 5384, 3704 and 4666), *Bala Ma wee* (3598, 6149), *Heen Horana Ma wee* (*3608*), *Horana Ma wee* (3625 and 3649) and *Kuru Ma wee Samba* (4435) explained the significant increase of grains per panicle with reduced days to flowering under EM.

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