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Research Paper

Relationship of Rate of Dry Matter Remobilization on Harvest Index and Yield of Medium Aged Rice Varieties

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Abstract: Rapid human population growth required more rice in future. Thus, it is important to increase yield potential of future rice varieties. As a physiological approach increasing rate of remobilization of assimilate as non-structural carbon to panicle, varietal variation of assimilate partitioning, quantify subsequent remobilization from leaf, sheath and stem to panicle, impact on partitioned dry matter on yield and harvest index are important to study. The field experiment was conducted in 3 consecutive seasons from 2020/21 Maha to 2021 Yala seasons in Rice Research and Development Institute (RRDI), Batalagoda. Fifteen rice varieties were screened under irrigated condition. All cultural practices were done according to Department of Agriculture recommendations. Rate of Remobilization of Dry Matter (RRDM) of leaf, sheath and stem were calculated from flowering to maturity. All agronomic data were analyzed using STAR computer package (Statistical Tool for Agricultural Research, 2014) of IRRI, Philippines for general linear model, Duncan mean separation, Principal Component Analysis. Important yield related parameters clearly separated by stepwise regression analysis by model with strong R2, grain yield explained RRDM leaf and stem, total soluble solid in stem (brix value). Bw 367 and Bg 370 have most efficient translocation system among the tested varieties. Total soluble solid content of stem (Brix value) with harvest index are most suitable parameters that explain an efficient source sink balance as a phenotypic trait. Dry matter remobilization rate in stem and total soluble solid content of stem with greater harvest index are the most suitable phenotypic traits to break through the yield potential in rice breeding programs.

Keywords: Rate of remobilization, Rice, Yield, Yield component

Introduction

Rice is the major carbohydrate source as well as staple diet of the community of Sri Lanka. It cultivates around 1,200,00 ha annually that is accounting for 34 % of the total cultivated lands in the country (Central Bank of Sri Lanka, 2019) and 1.8 million farm families are engaging and produce 4.5 t ha-1 average grain yield. It is important to increase yield potential of rice to feed future the human population. To increase yield potential exploring physiological factors that influence grain yield is a requirement. Among the different physiological factors sink and source interactions must play an important role (Patrik, 1988). However, amount of assimilate translocation to the panicle is regulates the grain filling, harvest index and subsequent yield formation. Harvest index is the ratio between grain yield and total shoot biomass (Donald and Hamblin, 1976). It is a novel feature which contributed the productivity of crop supply food for increasing population (Asefa, 2019). Harvest index is clearly explaining the sink source balance (Saito et al., 2021).

However, before anthesis assimilates produced by leaves are temporally stored in vegetative parts (Masoni et al., 2006). Photosynthate which are stored in vegetative organs at pre anthesis are remobilized in different rates in different crops. In wheat remobilization of pre anthesis dry matter varied from 7 to 57 % (Austin et al., 1977, Masoni et al., 2007), spring barley it was varied from 4 to 24 % (Arduini et al., 2006). Liu et al., (2017), reported that post anthesis dry matter remobilization of rice is 30 %. Jiang et al., (2022), found that, sugar partitioning signaling promoted by sink strength of panicle, which generate remobilization of mobilizable sugar content from stem to panicle. However, research findings on varietal differences of remobilization of stored dry matter to panicle are deficient in Sri Lanka. This study was aim to find varietal variation of assimilate partitioning, quantify subsequent remobilization from leaf, sheath and stem to panicle and impact on partitioned dry matter on yield and harvest index.

Materials and Methods

The field experiment was conducted in 3 consecutive seasons from 2020/21 Maha to 2021 Yala seasons in Rice Research and Development Institute (RRDI), Batalagoda. Fifteen rice varieties were screened (Table 1) under irrigated condition.

Table 1. Mean yield and harvest index of tested medium aged (100-109 days) rice varieties and breeding stations

Number	variety	Mean yield (tha^{-1})	Harvest Index	Station released
1	Bg 17 R	6.0	0.6	Batalagoda
2	At 373	4.9	0.5	Ambalantota
3	Bg 352	4.9	05	Batalagoda
4	Bg 357	5.8	0.6	Batalagoda
5	Bg 358	4.8	0.5	Batalagoda
6	Bg 359	5.9	0.6	Batalagoda
7	Bg 360	4.2	0.6	Batalagoda
8	Bg 366	6.0	0.6	Batalagoda
9	Bg 369	5.5	0.6	Batalagoda
10	Bg 370	5.4	0.6	Batalagoda
11	Bg 374	5.8	0.6	Batalagoda
12	Bg 94-1	4.1	0.6	Batalagoda
13	Bw 367	5.2	0.6	Bombuwala
14	Ld 368	4.6	0.6	Labuduwa
15	Bw 372	4.2	0.6	Bombuwala

Field was ploughed by disk plough and after 10 days harrowing was done by rotovator and properly leveled. Each plot (6 m x 3 m) were arranged and 16 days old, 2 to 3 seedlings were planted by 20 cm between row and 15 cm within row spacing as Randomized Complete Block Design with 3 replications. Urea, TSP and MOP fertilizers were used to fertilize the plots as the Department of Agriculture fertilizer recommendation (https://doa.gov.lk/fertilizer-recommendation).
Weed management was done by application of post emergence herbicide followed by hand weeding of remaining weeds. At late booting stage and physiological maturity 9 hills per each plot (3 hills x 3 hills) were uprooted separately and washed using fresh water. Root part was carefully removed and leaf, sheath and stem were partitioned. Samples were air dried 3 days and oven dried under 60 °C up to becoming a constant dry weight as per hill. Remobilization of Dry Matter (RDM) of each part (leaf, sheath and stem) were calculated using substation of total dry matter at late booting from partitioned dry matter of leaf, sheath and stem at physiological maturity as described by Masoni et al., (2006). Remobilized dry matter values for leaf, sheath and stem were divided by final weight of each part and considered as Rate of Remobilized Dry Matter (RRDM). Based on 9 hills plants, leaf, sheath, stem and panicle data harvest index was calculated. Further, separate plant was uprooted and removed root part, then separated small portion of the leaf, sheath and stem separately, crushed and squeeze the droplet to measure the brix value (%) using hand held refractometer. Grain yield of each plot was harvested, air dried up to 13 % seed moisture filled grains and unfilled grains were separated by winnowing and weight of filled seeds were converted to t ha-1. All agronomic data were analyzed using STAR computer package

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(Statistical Tool for Agricultural Research, 2014) of IRRI, Philippines as general linear model and Duncan mean separation was done. Principle Component Analysis was done using STAR computer package and biplot was present to explain relationship of biomass partitioning and remobilization of dry matter of each part on yield and harvest index.

Results and Discussion

Biomass partitioning at late booting

Main effect of varietal performances of above ground biomass partitioning among leaf, sheath and stem across the seasons are explained in Table 2. Leaf biomass did not significant among the varieties, seasons. Interaction effect between variety and seasons for leaf biomass also not significant (Table 2). Table 2 explained that, sheath biomass did not significant among the varieties, biomass content among the seasons was significant. However, interaction between variety and seasons did not significant. Stem biomass was significantly different among the season and varieties however, interaction between seasons into variety was not significantly different (Table 2).

Table 2. Main effect of above ground biomass partitioning among leaf, sheath and stem across the seasons.

Variety	Leaf dry weight (g m^{-2})	Sheath dry weight (g m^{-2})	Stem dry weight (g m^{-2})
Bg 17R	209.3^{a}	174.2^{a}	151.7 ^{bcd}
At 373	146.1^{a}	140.0^{a}	83.0 ^{f}
Bg 352	133.1^{a}	140.1^{a}	117.0 ^{bcdef}
Bg 357	127.1^{a}	120.6^{a}	92.0^{f}
Bg 358	155.0^{a}	178.5^{a}	160.3 ^{bc}
Bg 359	148.8^{a}	160.1^{a}	106.7 ^{def}
Bg 360	143.6^{a}	118.7^{a}	88.7 ^{f}
Bg 366	142.6^{a}	131.5^{a}	116.0 ^{cdef}
Bg 369	140.9^{a}	175.0^{a}	151.3 ^{bcd}
Bg 370	133.4^{a}	113.1^{a}	112.0 ^{de}f
Bg 374	159.9^{a}	197.2^{a}	139.0 ^{bcde}
Bg 94-1	143.7^{a}	162.6^{a}	99.0 ^{ef}
Bw 367	165.6^{a}	254.9^{a}	150.3 ^{bcd}
Ld 368	172.9^{a}	155.9^{a}	211.0 ^{a}
Bw 372	149.4^{a}	171.3^{a}	163.7 ^{b}
CV %	35.2	59.5	33.6
Pr > f (v)	0.22	0.21	0.001
Pr > f (S)	0.33	0.001	0.001
Pr > f (V x S)	0.68	0.63	0.06

Note: means with same letters are not significantly different at p = 0.05, S – season, V – variety (seasonal averages did not compare in the table)

The highest stem biomass was recorded in Ld368 (211.0 gm -2). The lowest stem biomass recorded in At 373, Bg 357 and Bg 360 (83.0, 92.0 and 88.7 gm -2 respectively).

Rate of remobilized dry matter (RRDM) content of leaf, sheath and stem

RRDM content among the season, plant organ (leaf, sheath and stem) and variety explained by significantly different at > 0.001, > 0.001 and 0.004 respectively. Interaction of season, variety and position/organ (> 0.001) also significantly different (data not shown in table). Table 3 explained that, RRDM of leaf and sheath did not significant in every season but, RRDM of stem was significantly different in every season as 0.003, 0.0.5 and 0.001 respectively. Varietal response of leaf RRDM was significantly different only in Yala season. When considering sheath RRDM varietal variation occurred in 2021/22 Maha season. However, stem RRDM significantly different in all tested seasons. Those result suggested that, there was seasonal variations were occurred on rate of remobilized dry matter content among the different organs.

Table 3 further explained that, at least one Yala and one Maha over 0.60 RRDM from stem were recorded in Bg 94-1, Bg 370, Bg 357, Bg 359, Bw367, Bg 366 and Bg 17R varieties. Further, 2021/22 Maha season amount of RRDM from stem was lower in every varieties. Brix values of leaf, sheath and stem at late booting stage of selected varieties, organ of sampling (leaf, sheath and stem) explained in Table 4. Main effect showed significantly differences such as < 0.001 for variety and organ, interaction of variety and organ 0.0001 (Table 4). Brix values were statistical signifies were compared among the tissue types. Table 4 explained that, the highest average of brix value across stem. Sheath and leaf recorded in Bg 370, Bg 366 (10.0) and Bw 367 (9.4) and followed by Bg 17 R (9.4). Average brix value of leaf, sheath and stem across the varieties are 8.6, 5.8 and 8.4 respectively. Therefore, RRDM data and Brix values suggested that, Bg370, Bg 366, Bw 367 and 17 R varieties are highly efficient total soluble solid transporting varieties and they can efficiently remobilized dry matter at grain filling stage.

Table 3. Varietal variation of remobilized dry matter content of leaf, sheath and stem as the rate of non-structural: structural carbon and seasonal response and main effect.

Variety	2020/21maha			2021/22maha			2022yala		
	Leaf	sheath	stem	Leaf	sheath	stem	Leaf	sheath	stem
At 373	0.33 ab	0.73 a	0.56 abc	0.36 ab	0.37 bc	0.35 abc	0.37 cd	0.20 ab	0.83 b
Bg 352	0.40 ab	0.67 a	0.30 abc	0.45 ab	0.37 bc	0.27 abc	0.48 abcd	0.27 ab	0.71 b
Bg 357	0.37 ab	0.56 a	0.82 a	0.50 ab	0.43 bc	0.45 abc	0.46 bcd	0.25 ab	0.65 b
Bg 358	0.54 ab	0.50 a	0.39 c	0.59 ab	0.44 bc	0.21 bc	0.38 cd	0.13 ab	0.71 b
Bg 359	0.42 ab	0.74 a	0.65 ab	0.32 b	0.26 c	0.49 ab	0.38 cd	0.13 ab	0.78 b
Bg 360	0.27 b	0.73 a	0.60 ab	0.43 ab	0.48 bc	0.41 abc	0.53 abc	0.27 ab	0.54 b
Bg 366	0.35 ab	0.71 a	0.61 abc	0.44 ab	0.62 b	0.38 abc	0.42 bcd	0.31 ab	0.81 b
Bg 369	0.59 ab	0.60 a	0.58 abc	0.67 ab	0.48 bc	0.38 abc	0.66 ab	0.21 ab	0.48 b
Bg 370	0.32 ab	0.71 a	0.82 a	0.62 ab	0.34 bc	0.36 abc	0.73 a	0.39 a	0.83 b
Bg 374	0.36 ab	0.46 a	0.76 ab	0.43 ab	0.43 bc	0.37 abc	0.45 bcd	0.13 ab	0.66 b
Bg 94-1	0.46 ab	0.58 a	0.71 ab	0.39 ab	0.27 c	0.53 a	0.38 bcd	0.12 b	0.95 a
Bw 367	0.48 ab	0.61 a	0.67 ab	0.69 ab	0.54 b	0.19 bc	0.48 abcd	0.10 b	0.89 ab
Ld 368	0.45 ab	0.69 a	0.53 bc	0.34 ab	0.82 a	0.13 c	0.30 d	0.39 a	0.38 b
Bw 372	0.60 a	0.58 a	0.53 bc	0.65 ab	0.48 bc	0.44 abc	0.62 ab	0.32 ab	0.50 b
Bg 17 R	0.31 b	0.44 a	0.62 bc	0.41 ab	0.39 cd	0.36 abc	0.27 d	0.26 ab	0.64 b
CV %	36.0	30.9	16.5	37.5	26	26.7	26.7	30.1	30.8
P_r>f	0.31	0.63	0.003	0.23	0.001	0.05	0.003	0.18	0.001

Note: means with same letters are not significantly different at p ≥ 0.05

Table 4. Tissue level differences in Brix value of varieties studied

Variety	Leaf	Sheath	Stem	Overall average
Bg 17R	9.3 a	6.3 b	9.3 a	8.3 b
At 373	7.6 a	4.3 b	6.6 a	6.2 efg

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Bg 352	7.0 ^{a}	3.3 ^{b}	5.6 ^{a}	5.3 ^{g}
Bg357	7.3 ^{a}	5.3 ^{b}	8.6 ^{a}	7.1 ^{bcdef}
Bg 358	7.0 ^{ab}	4.6 ^{b}	10.0 ^{a}	7.2 ^{bcde}
Bg359	8.3 ^{b}	6.3 ^{c}	10.0 ^{a}	8.2 ^{bc}
Bg 360	9.0 ^{a}	6.6 ^{b}	8.0 ^{ab}	7.8 ^{bcd}
Bg 366	14.0 ^{ab}	8.6 ^{b}	11.3 ^{a}	10.0 ^{a}
Bg 369	10.3 ^{a}	5.6 ^{c}	7.6 ^{b}	7.8 ^{bcd}
Bg 370	11.6 ^{a}	10.0 ^{a}	9.0 ^{a}	10.2 ^{a}
Bg 374	9.0 ^{a}	4.6 ^{c}	7.0 ^{b}	6.8 ^{ef}
Bg 94-1	7.0 ^{a}	4.0 ^{c}	8.3 ^{a}	6.4 ^{efg}
Bw 367	10.0 ^{a}	9.0 ^{a}	9.3 ^{a}	9.4 ^{a}
Bw 372	6.0 ^{b}	4.0 ^{c}	8.0 ^{a}	6.0 ^{fg}
Ld 368	9.3 ^{a}	5.0 ^{c}	7.3 ^{ab}	7.2 ^{bcde}
Average of position	8.6 a	5.8 b	8.4 a	
CV %				14.0

Note: means with same letters are not significantly different at p ≥ 0.05.

Grain yield

Grain yield was significantly different among the varieties, season and season into variety interaction (Table 5). The highest grain yield recorded in Bg 359, Bg 370 and Bg 366 as per 4.70, 4.96 and 5.62 t ha-1 in 20/21 Maha, 21/22 Maha and 2021 Yala seasons respectively. When compared to tested seasons. At 373 recorded the lowest grain yield asper 2.64, 3.32 and 3.74 t ha-1 in 2020/21 Maha, 2021/22 Maha and 2021 Yala seasons respectively.

Table 5. Grain yield and harvest index of different varieties from 2020/21 Maha to 2021 Yala seasons

Variety	20 /21Maha		21/22Maha		21 Yala	
	Average grain yield (t ha^{-1})	Harvest Index	Average grain yield (t ha^{-1})	Harvest Index	Average grain yield (t ha^{-1})	Harvest Index
Bg 17R	4.14 ^{abcd}	0.56 ^{ab}	4.26 ^{abc}	0.59 ^{a}	3.23 c	0.65 ^{a}
At 373	2.64 ^{e}	0.48 ^{b}	3.32 ^{d}	0.49 ^{b}	3.74 ^{cde}	0.46 ^{c}
Bg 352	3.39 ^{cde}	0.50 ^{b}	1.7 ^{e}	0.50 ^{b}	4.23 ^{bc}	0.55 ^{b}
Bg 357	4.34 ^{ab}	0.62 ^{a}	4.35 ^{abc}	0.59 ^{ab}	4.48 ^{bc}	0.69 ^{a}
Bg 358	4.13 ^{abcd}	0.53 ^{ab}	4.24 ^{abc}	0.51 ^{b}	4.58 ^{bc}	0.53 ^{b}
Bg 359	4.7 ^{a}	0.63 ^{a}	3.96 ^{bcd}	0.63 ^{a}	4.94 ^{ab}	0.63 ^{ab}
Bg 360	3.8 ^{bcd}	0.50 ^{b}	3.68 ^{cd}	0.62 ^{a}	3.39 ^{de}	0.59 ^{ab}
Bg 366	3.35 ^{de}	0.55 ^{ab}	3.58 ^{cd}	0.55 ^{ab}	5.62 ^{a}	0.61 ^{ab}
Bg 369	4.26 ^{abc}	0.61 ^{a}	3.93 ^{bcd}	0.60 ^{a}	4.63 ^{b}	0.69 ^{a}
Bg 370	4.18 ^{abcd}	0.58 ^{ab}	4.96 ^{a}	0.60 ^{a}	4.63 ^{b}	0.63 ^{ab}
Bg 374	4.38 ^{ab}	0.55 ^{ab}	4.63 ^{ab}	0.60 ^{a}	4.68 ^{b}	0.60 ^{ab}

Bg 94-1	4.09 abcd	0.59 ab	3.83 bcd	0.59 ab	4.62 b	0.63 ab
Bw 367	4.44 ab	0.57 ab	4.28 abc	0.56 ab	4.43 bc	0.67 a
Ld 368	4.16 abcd	0.58 ab	4.06 bcd	0.57 ab	4.25 bc	0.69 a
Bw 372	4.58 ab	0.55 b	4.28 abc	0.54 b	4.14 bcd	0.61 b

Note: means with same letters are not significantly different at p = 0.05, S – season, V – variety

Harvest Index

Harvest index is a good indicator which explains the sink and source relationship of the variety, ratio between yield and vegetative parts and genetic, environment & management of the crop (Poker et al., 2020). Table 5 explained that, harvest index of varieties and seasons were significantly different and interaction between season into variety did not significant (0.001, 0.001 and 0.08 respectively). Bg 17R, Bg 357, Bg359, Bg366, Bg 369, Bg370, Bg 374, Bg 94-1, Bw 367, Ld 368 and Bw 372 varieties showed greater harvest index in tested seasons. However, stable yield over 3 seasons greater than 4 t ha^{-1} were recorded in Bg357, Bg358, Bg370, Bw367 and Bw 367 varieties. However, stable harvest index 0.6 or above over 3 seasons recorded in Bg359.

Table 5. Eigen value, proportion and cumulative percentage of principle components

Principal component	Eigen value	Proportion %	Cumulative %
1	2.70	30.0	30.0
2	2.23	24.8	54.8
3	1.56	17.4	72.2
4	1.13	12.6	84.8

Principal component analysis explained by tested biomass partitioning related nine traits. Figure 2, revealed that, there were significant impact on variety and growing season on harvest index (Pr > f, 0.001 respectively). However, interaction between variety and growing season was not significant. According to the Figure 1, the highest harvest index recorded in Bg 369 (0.66) and the lowest was At 373 (0.47). Above data suggested that, Bg 369 has greater sheath remobilization rate compared to stem and leaf. Bw 367, Ld 368 and 17 R varieties also obtain the comparable harvest index than Bg 369. variance explained by first four principal components (PC).

Table 6. Loading of PC score dry matter partitioning related traits in 4 PCs

Principle component	Variable	coefficient
PC1	Leaf biomass	-0.50
	Stem biomass	-0.46
	RRDM leaf	-0.47
PC2	Brix leaf	-0.52
	Brix sheath	-0.58
	Brix stem	-0.47
PC3	RRDM sheath	0.62
	RRDM stem	0.71
PC4	Sheath biomass	0.67

Note: RRDM – rate of remobilized dry matter

Table 6 explained that, 1st principal component (PC1) highly loaded by leaf biomass, stem biomass and rate of remobilized dry matter by -0.50, -0.46 and -0.47. However, bi plot results of PC1 Vs PC2 explained that, PC1 loaded by leaf biomass, stem biomass and rate of remobilized dry matter from average grain yield over seasons 3.47 and 4.15 respectively for Bg 17R and Ld 368. PC2 highly loaded brix values of leaf, sheath and stem by -0.52, -0.58 and -0.47 respectively (Table 6) and biplot explained that, loading of brix values leaf, sheath and stem by -2, -3 and -3. Further, Bg 366 highly correlated to brix values with more than -0.4 score). Bw 367 and Bg 370 also loaded in PC2 by -0.2 and -0.4 score but cosine values with brix loading were lower than that of Bg 366 (Figure 2a). Table 5 and Figure 1, explained that, Bg 366, Bw 367 and Bg 370 recorded average yield over seasons around 4.18, 4.59 and 4.38 respectively and harvest index over seasons around 0.57, 0.6 and 0.6 respectively. This cluster performed high yield and high harvest index. According to Table 06, rate of remobilized dry matter from sheath and stem highly loaded in PC3 by 0.62 and 0.72 respectively. Further, Bg 369, Bg 370 and Bg 374 varieties positively loaded on 0.4, 0.5 and > 0.2 PC score and RRDMSh and RRDMSt loading facters were 0.3 and 0.4 respectively (Figure 2b). there was no clear clustering of Bg 369, Bg 370 and Bg 374 in dendogram (Figure 3).

According to table 5, average yield over the seasons in Bg 369, Bg 370 and Bg 374 were obtained 4.2, 4.6 and 4.6 tha-1 respectively (table 6). Figure 2 explained that, harvest index of Bg 369, Bg 370 and Bg 366 were 0.66, 0.61 and 0.59 respectively. PC4 explained that sheath biomass loaded as 0.67 coefficient and sheath biomass 12.6 % of total varability (Table 5 and 6). Further, those varieties obtained average yield over season 4.2, 4.5, 4.3 and 4.3 respectively and harvest index over seasons leaf by more than -2 loading and highly correlated on Bg 17 R and Ld 368 0.4 and 0.2 scores (Figure 2a). These two varieties were clustered significantly (Willk's and Roy's test > 0.001) together at 5.20 cluster distance (Figure 3). Average Harvest index of this cluster approximately 0.6 but 0.69, 0.59, 0.6 and 0.57 respectively (Table 5 and Figure 2). Hierarchial clustering of testerd varieties were clustered under compleate linkage and Euclidean distance (Figure 3). According to result of the cluster analysis, Euclidean distances for seperating each clusteres were varied. Cluster one and two were seperated at 5.1, second to third clusters were seperated at 5.11, third to fourth clusters were seperated at 4.51. According to MANOVA test clusters were significantly different under Will's test and Lawley Hotelling test at 0.001 and 0.005 probebility levels.

Important harvest index and yield related parameters

Table 7 explained that, stepwise regression analysis of grain yield with nine parameters across 15 varieties showed significant relationship by (f (1,13) = 80.97, p<0.0001). The intercept of the final model was significant at p < 0.0001 and r2 was 0.93. Final model was selected the rate of remobilized dry matter of the leaf (RRDML), Brix value of the stem (BrixSt), rate of remobilized dry matter from the stem (RRDMST) consistent with the parameter estimates -0.01, 2.5 and 0.21 respectively. According to principle component analysis (Table 6) first three principle components were contributed on yield formation. Table 8. explained that, stepwise regression analysis of harvest index against the nine parameters across 15 varieties showed significant relationship by (f (1,13) = 353.1, p<0.0001). The intercept of the final model was not significant at p<0.23 and r2 was 0.97.

Table 7. Parameter estimate and significance of variables on yield

Variable	PE	Partial R^2	Model R^2	C(p)	Pr > F
Intercept	0.41				
RRDML	-0.01	0.86	0.86	4.86	<.0001
Brix St	2.5	0.05	0.92	0.72	0.02
RRDMST	0.21	0.02	0.94	0.42	0.09

Note: PE- parameter estimate, RRDML- rate of remobilized dry matter from leaf, RRDMST- rate of remobilized dry matter from stem, BrixSt- brix value in stem

According to Table 8, leaf dry weight and rate of remobilized dry matter contributed on harvest index with the parameter estimate 0.03 and 0.01 respectively. Therefore, these 2 parameters were represented in PC1 for formation of harvest index.

Table 8. Parameter estimate and significance of variables on Harvest index

Variable	PE	Partial R^2	Model R^2	C(p)	Pr > F
Intercept	-0.99				
RRDML	0.01	0.96	0.96	1.97	<.0001
LDWT	0.03	0.008	0.97	0.75	0.06

Note: PE- parameter estimate

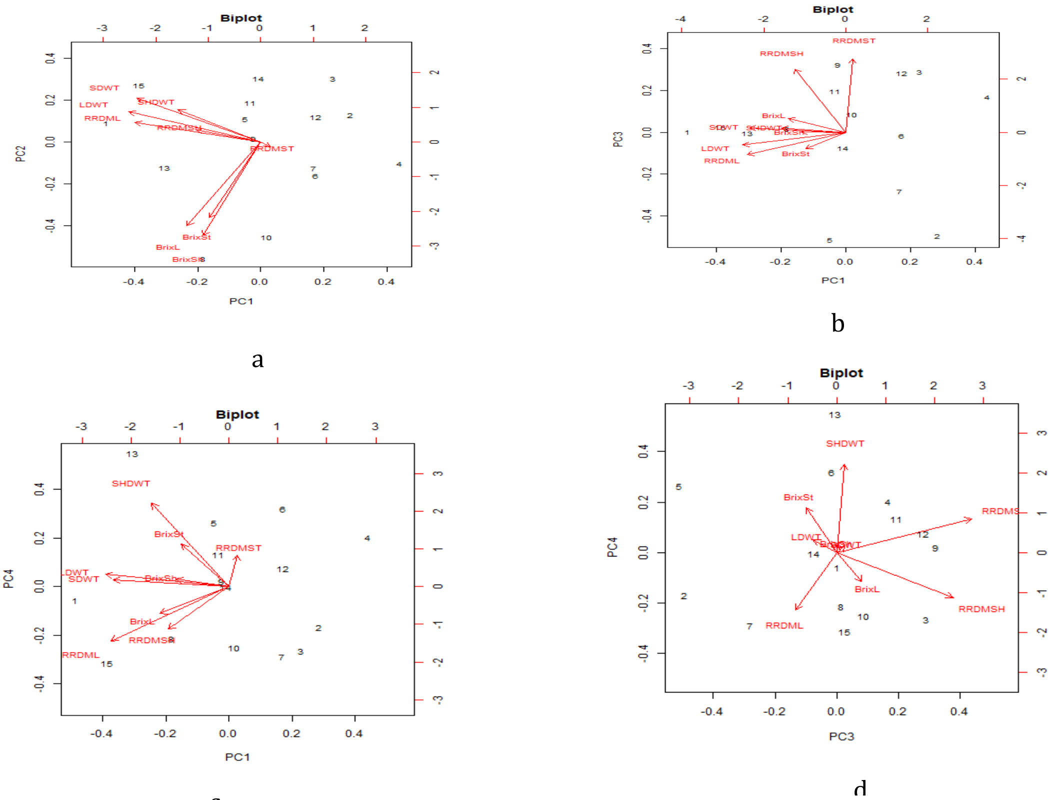

Figure 2. Bi plot of PC1 PC2, PC3 and PC4 loading of dry matter related traits and score of varieties.

(Varieties numbered as Table 1, loading traits LDWT- Leaf biomass, SHDWT- sheath biomass, SDWT- Stem biomass, RRDML- rate of remobilized dry matter from leaf, RRDMSH- rate of remobilized dry matter from sheath, RRDMST- Bi plot explained that, sheath biomass loaded around 0.4, Bg 369, Bw 372, Bg 374 and Bw 367 varieties scored 0.0, 0.0, 0.1 and >0.4 respectively (Figure 2c). Rate of remobilized dry matter from stem, BrixL- brix value in leaf, BrixSh- brix value in sheath, BrixSt- brix value in stem).

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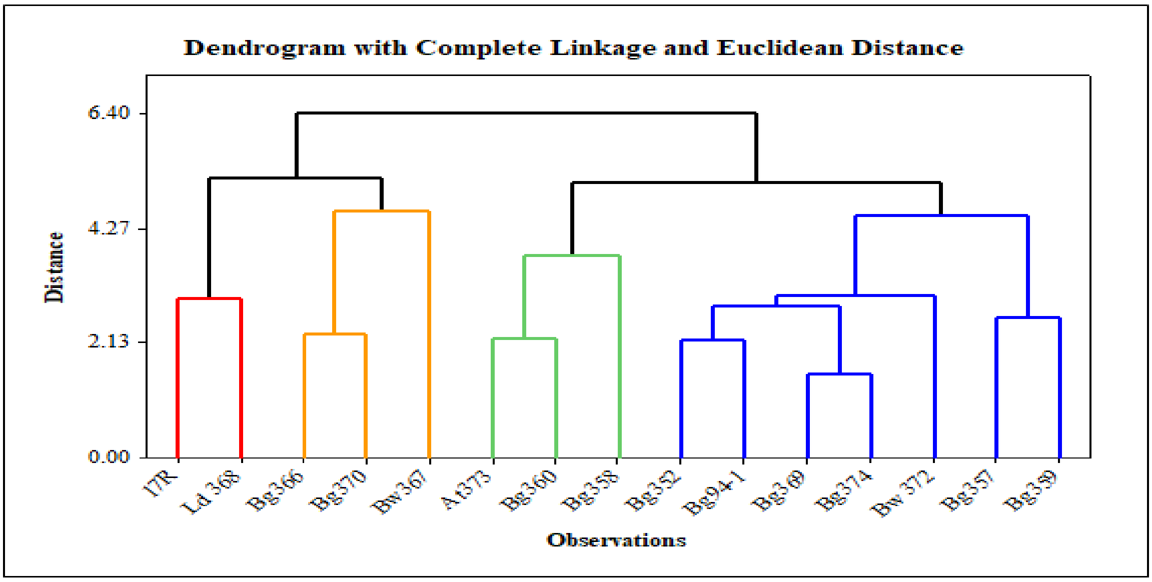

Figure 3. Dendrogram of varietal loading as different clusters obtained by cluster analysis

DISCUSSION

Photosynthesis and rice growth govern by leaf area index, leaf nitrogen content, leaf anatomy and efficient assimilate translocation. Leaves play a significant role in assimilate production. However, biomass partitioning explained that, among the tested medium age rice varieties and seasons leaf biomass is more or less similar. But seasonal variations in leaf sheath biomass and stem biomass showed varietal and seasonal variations. Seasonal variations suggested that, climatic parameters such as temperature could be affected biomass accumulation of stem and leaf sheath. However, contrasting result was observed by Mahmood et al., (2023) as a short-term heat stress at reproductive phase slightly affect on biomass partitioning. However, seasonal variations of biomass accumulation in our finding suggested that, amount of biomass accumulation at vegetative stage had significant impact on seasonal climatic variations. Wakabayashi et al, (2022) reported that, biomass partitioning differences mainly govern the nonstructural carbohydrate accumulation. Further, lower leaf sheaths are highly adapted to supply nonstructural sugars for tiller development at vegetative stage. Fujitha and Yoshida (1984) explained that, biomass accumulation ability of leaf sheath is declined before heading. However, non structural carbohydrate is the main reserves in the stem, it was accumulated in stem prior to anthesis and translocated to panicle at grain filling (Fischer, 1985). Sugar signaling of stem for remobilization encouraged by sink strength of rice grains (Jiang et al., 2022). Wakabayashi et al, (2022) revealed that, before anthesis non-structural carbon will accumulate in sink tissues (leaf sheath, stem and roots) and while grain filling newly produced photosynthate as well as accumulated non-structural carbon will translocated to grain as a carbon source after heading. Therefore, it was suggested that, considerable amount of non-structural carbohydrate will be remobilized from leaf, sheath and stem at grain filling. However, irrespective of the season and variety leaf and sheath showed greater dry matter remobilization to panicle compared with the structural weight of leaf and sheath. However, varietal responses are varied, whereas Bg352, Bg 17 R, Bg 369, Bg 374, Bg 370 and Bw 367 showed significantly greater RRDM (more than 0.80) in irrespective to season and plant position (Table 3). However, mechanism of non-structural carbon (sucrose) accumulation of rice is unclear. In general ethanol extraction method is used for measuring sugar content but brix value of the stem juice has a clear correlation (r = 0.958) with soluble solid (Okamura et al., 2016). Among varietal effect of RRDM irrespective to the season and organs for brix value (Table 4) Bg 370, Bw 367 and Bg 366 showed greater translocation from leaf sheath, it was reflected that, these varieties should provide nonstructural carbon not only for tiller development (Wakabayashi et al, 2022) but also provide non-structural carbon for post anthesis grain filing. Further, Bg 370, Bw 367 and Bg 366 clustered separately at 4.27 Euclidean distance and principle component analysis and bi plot data clearly explained these variations. However, grain yield of Bg 366 lower than Bw 367 and Bg 370. This contrasting result of Bg 366 will be due to lower harvest index. The significantly lowest RRDM recorded in At 373 (0.74) irrespective to season and position of the plant (Table 3) which explained by lower yield and harvest index. Therefore, result suggested that leaf and sheath are the most efficient parts which translocate non-structural carbohydrate compared to total (structural and non-structural) carbohydrate. Leaf blade is the source and storage organ which is supply same amount of non-structural carbohydrate to sink. Bw367 and Ld 368 can translocate same amount of non-structural carbohydrate from leaf, sheath as well as stem but brix value of Ld 368 was significantly lower, thus this variety provided greater assimilate for tiller production before late booting. Important yield related parameters clearly separated by stepwise regression analysis by model with strong R2, among the tested parameters grain yield explained only the RRDM leaf and stem and total soluble solid in stem (brix value). Next model was clearly explained that, RRDM leaf and leaf dry weight strongly explained the harvest index. Therefore, Bw 367 and Bg 370 have most efficient translocation system among the tested varieties. Further, this efficiency did not clearly explain by moderate harvest index (0.6). Therefore, this paper highlighted that, harvest index alone did not clearly explain the sink source balance, rate of dry matter remobilization. Thus, total soluble solid content of stem (Brix value) with harvest index are most suitable parameters that explain an efficient source sink balance as a phenotypic trait. Further research is needed to gene expression studies for sucrose transporter genes for phloem loading and invertases for phloem unloading in grains as well as grain filling related genes. Therefore, dry matter remobilization rate in stem and total soluble solid content of stem (Brix value) with greater harvest index are the most suitable phenotypic traits to break through the yield potential in rice breeding programs.

CONCLUSION

Varieties having greater rate of remobilization rate compared to accumulated biomass at late booting stage of leaf, stem and greater total soluble solid content of stem can be select as physiologically efficient high yielding varieties. Bw 367 and Bg 370 are the most efficient translocating varieties which can produce greater post anthesis assimilate and directly translocate to panicle. These varieties should be used as a parent for development of large panicle varieties for breakthrough the yield potential.

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