Evaluation of altered biomass mutant contributing increased grain yield in rice (*Oryza sativa* L.)

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Abstract

Yield improvement through crop breeding is a constant process to meet increasing yield demand in context of decreasing cultivable land and erratic climatic conditions. Breeding for yield improvement can be achieved through altering plant type. Improving plant biomass can pave way for improving grain yield as grain yield is product of biomass and harvest index. EMS induced mutants serve as a source for creating novel variations for altering plant type. In this view, EMS mutant of Nagina 22 was identified with altered biomass and grain yield. A mapping population of N22 x N22-CC-M4-HT -1333 was studied in F₂ and F₃ for traits contributing for altered biomass and grain yield. The correlation analysis in F₂ and F₃ showed that dry matter produced was significantly correlated with grain yield showing the increase in grain yield of the mutant was contributed by dry biomass. This mutant is potential for unraveling the novel ways to improve grain yield and further functional genomics studies.

Keywords

mutant, altered biomass, grain yield, variability, correlation, rice

INTRODUCTION

Rice is staple food crop for 3.5 billion people across the globe covering major countries of Asia, Africa (GRiSP, 2013). By 2050, the estimated increase of total global population will be 9.7 billion from 7.6 billion populations. This demands an increase of 100 % crop yield increase in major food crops (FAO, 2015). This necessitates an increase in rice production - through breeding of high yielding varieties, improved agronomic practices in spite of erratic climate and shrinking cultivable land. First phase leap of yield increase was through green revolution by introducing semi dwarf rice varieties and improved fertilizer usage. This gave yield increase from 6 to 10 t/ha. Later, the second leap in yield was due to hybrids with increased grain yield and heterosis. Again the yield increase has attained plateau and further developments should have novel breeding methods. Grain yield is process of dry matter accumulation and distribution. Grain yield is product of biomass and harvest index (Wu et al., 2008). Hence, future thrust of breeding for yield improvement can be planned based on increasing biomass or harvest index.

The varieties released from IRRI prior to 1980 were reported to have high harvest index leading to yield increase. The yield increase in varieties released after 1980 were due to increased aboveground biomass and concluded that future breeding to increase yield can be fruitful by improving biomass (Peng et al., 2000). New plant type concept introduced in IRRI for improving the yield through modifying the plant architecture (Khush, 1995). This can be used to improve lodging resistance, improving sink capacity and less unproductive tillers. This
led to breeding of cultivars having large panicles with few unproductive tillers but the grain yield was poor. This was reported due to poor aboveground biomass and poor grain filling. In breeding for second generation NPT, increased tilling capacity, pest and disease resistance were identified to improve grain yield. This resulted in high yield than Indica check and increased yield was associated with increased aboveground biomass and grain weight (Peng et al., 2008). Super hybrid rice Liangyoupeijiu reported to have 12% hike in above ground total biomass than Shanyou63. The high biomass was associated with high leaf area index, leaf area duration, thick leaf, high chlorophyll content and photosynthetic rate. The increased yield of Liangyoupeijiu was due to high leaf area duration before heading, biomass accumulation before heading, number of grains and more translocation of carbohydrates from source to sink during grain filling period (Katsura et al., 2007). In this view, an attempt was made to characterize the altered biomass mutant of Nagina 22. EMS treated N22 mutant screened for altered plant architecture resulted in identifying a mutant and named as N22-CC-M4-HT-1333. This was characterized for tillering capacity, pest and disease resistance were reported due to poor aboveground biomass and poor grain seedling vigour, crop growth rate to identify the biomass of N22-CC-M4-HT-1333 in comparison with N22. It was also studied in F2, and F3 generation of mapping population of N22 x N22-HT-1333.

MATERIALS AND METHOD

The research was focused to exploit the altered biomass mutant N22-CC-M4-HT-1333 in terms of biomass accumulation. The traits contributing for increased biomass accumulation and grain yield pertinent to mutant was studied using F2 and F3 of N22 x N22-CC-M4-HT-1333 mapping population. The study was carried at Department of Rice, Centre for plant breeding and Genetics, Tamil Nadu Agricultural University, Coimbatore during 2018-2019. One hundred and forty plants were raised in F2 in 20 cm x 20 cm spacing and evaluated for biometrical traits. The 140 F2 families were raised from F3 as ear to row method. Each family was raised in two rows in 2.4 m row with a spacing of 20 cm x 20 cm. Three plants per family were tagged and a total of 420 plants in F3 were evaluated for biometrical traits. The plants were observed for plant height, number of tillers and productive tillers, days to fifty per cent flowering, flag leaf length, flag leaf width, panicle length, third leaf length, third leaf breadth, third leaf weight, leaf area, specific leaf weight, wet biomass, dry matter produced, harvest index and single plant yield. The data were collected and analyzed for the estimation of phenotypic and genotypic coefficients of variation as suggested by Burton (1952). Heritability was estimated according to Lush (1940) and genetic advance as percentage of mean was calculated according to Johnson et al. (1955). The correlation was performed using R package (Pearson’s coefficient using Corrplot, v.0.84) and significant correlation coefficient was observed at 5 and 1 % level of significance.

RESULTS AND DISCUSSION

The phenotypic characterization for plant height, number of tillers, number of productive tillers, days to fifty per cent flowering, flag leaf length, flag leaf width, panicle length, third leaf length, third leaf breadth, third leaf weight, leaf area, specific leaf weight, wet biomass, dry matter produced, harvest index and single plant yield (Table 1). The dry matter production and grain yield has increased in N22-CC-M4-HT-1333 than N22 in both the seasons. This showed that the parent selected was efficient. This mutant parent needs to be evaluated more for the identification of dry mater produced. The dry matter accumulation increase may be attributed by crop growth rate and increased duration of crop growth (Yoshida, 1983). The biomass production during vegetative and grain filling stages contributed significantly for biomass (Ying, 1998). The higher biomass production may be due to prolonged growth duration in super hybrid rice (Zhang, 2009).

The phenotypic and genotypic coefficient of variation, heritability, genetic advance as percentage of mean are given in Table 1. In F2, the variability analysis for the characters like number of tillers, productive tillers per plant, Table 1. Range, mean, PCV, GCV, heritability(H), genetic advance as percentage of mean (GAM) in F2 and F3 population of N22 x N22-CC-M4-HT-1333

| Traits      | N22 | N22-CC-M4-HT-1333 | F2  | F3   |
|-------------|-----|-------------------|-----|------|
| H (%)       | 0.49| 0.26              | 0.43| 0.43 |
| GAM (%)     | 34.4| 32.5              | 34  | 34   |
| PCV (%)     | 46  | 43.6              | 45.3| 42.8 |
| GCV (%)     | 58.4| 49.62             | 47.5| 42.6 |
| H (%)       | 0.47| 0.47              | 0.47| 0.47 |
| GAM (%)     | 34  | 34                | 34  | 34   |

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third leaf length, leaf area, leaf weight, specific leaf area, specific leaf weight, wet biomass, dry matter produced and grain yield showed high PCV and GCV. The narrow variation of PCV and GCV in traits like leaf area, leaf weight, specific leaf area, specific leaf weight, wet biomass, dry matter produced and grain yield (Fig. 1). In F₂, number of tillers, productive tillers per plant, efficient tillering per cent, flag leaf length, panicle length, leaf area, leaf weight, wet biomass, dry matter produced and grain yield showed high PCV and GCV. Similar reports of high PCV and GCV were given by Tiwari (2015) and Singh et al. (2016) for productive tillers per plant, Priyanka et al. (2019) and Mamtha et al. (2018) for single plant yield in F₂ population, Khatun et al. (2015) for dry matter produced. These results make us to understand that these traits having variability contributed by genetic factors and less influenced by environment, hence selection for these traits may be fruitful. In F₂, the traits like efficient tillering percentage, flag leaf length and panicle length registered moderate PCV and GCV, whereas flag leaf width and harvest index showed moderate PCV and low GCV. This revealed that the former traits had comparatively less environmental influence than the later. In F₃, plant height, flag leaf width, third leaf length, third leaf breadth, specific leaf area, specific leaf weight, harvest index showed moderate PCV and GCV. Selection of these traits can be done based on heritability. The plant height in F₂ has low PCV and GCV showing that the variation for plant height is less and selection may not be rewarding. The traits viz., number of tillers, productive tillers, third leaf length leaf breadth, specific leaf area, and wet biomass and dry matter produced showed higher variability in F₂ compared to F₃ generation.

Table 2. Correlation coefficient in F₃ generation of population of N22 x N22-CC-M4-HT-1333

|       | PH | NT | NPT | FLL | FLW | PL | TLL | TLB | LW | WB | DMP | HI | GY |
|-------|----|----|-----|-----|-----|----|-----|-----|-----|-----|-----|----|----|
| PH    | 1.000 |    |     |     |     |    |     |     |     |     |     |    |    |
| NT    | 0.827** | 1.000 |     |     |     |    |     |     |     |     |     |    |    |
| NPT   | 0.855** | 0.961** | 1.000 |     |     |    |     |     |     |     |     |    |    |
| ETP   | 0.677* | 0.418 | 0.600* | 1.000 |     |    |     |     |     |     |     |    |    |
| FLL   | 0.636* | 0.696** | 0.728** | 1.000 |     |    |     |     |     |     |     |    |    |
| FLW   | 0.532 | 0.507 | 0.574* | 0.903 | 1.000 |    |     |     |     |     |     |    |    |
| PL    | 0.758** | 0.770** | 0.829** | 0.685** | 0.627 | 1.000 |     |     |     |     |     |    |    |
| TLL   | -0.239 | -0.306 | -0.311 | -0.219 | -0.121 | -0.283 | 1.000 |     |     |     |     |    |    |
| TLB   | -0.481 | -0.515 | -0.500 | -0.309 | -0.260 | -0.596 | 0.239 | 1.000 |     |     |     |    |    |
| LW    | -0.058 | -0.064 | -0.040 | -0.009 | 0.039 | -0.089 | 0.722** | 0.453 | 1.000 |     |     |    |    |
| WB    | 0.866** | 0.917** | 0.916** | 0.718** | 0.568 | 0.864** | -0.329 | -0.560 | -0.104 | 1.000 |     |    |    |
| DMP   | 0.861** | 0.926** | 0.929** | 0.742** | 0.610 | 0.897** | -0.239 | -0.576 | -0.089 | 0.966** | 1.000 |    |    |
| HI    | 0.014 | -0.085 | -0.061 | -0.091 | 0.049 | -0.020 | 0.081 | -0.031 | 0.004 | -0.078 | -0.066 | 1.000 |    |
| GY    | 0.852* | 0.860** | 0.877** | 0.691** | 0.620* | 0.869** | -0.235 | -0.574 | -0.067 | 0.909** | 0.947** | 0.231 | 1.000 |

*r_s=0.552, **r_s=0.683
Heritability and genetic advance as percentage of mean gives a picture of additive or non-additive gene action, thus it may be helpful in selection procedures. In this study, many traits showed high heritability and genetic advance. The traits like plant height, efficient tillering percent, flag leaf length, third leaf length, leaf area, specific leaf area, specific leaf weight, wet biomass, dry matter produced and grain yield showed high heritability and genetic advance in $F_2$ generation (Table 1, Fig. 2). In $F_3$, plant height, number of tillers, efficient tillering per cent, flag leaf length, flag leaf width, third leaf length, leaf weight, specific leaf area, wet biomass, dry matter produced, harvest index and grain yield expressed high heritability and genetic advance. This shows that these traits controlled by additive gene action and selection may be effective. Priyanka et al. (2019) and Mamtha et al. (2018) for single plant yield and Khatun et al. (2015) for dry matter produced had reported high heritability and genetic advance.

![Fig. 2. Heritability and genetic advance of seventeen characters in $F_2$ and $F_3$ population of N22 x N22-CC-M4-HT-1333](image)

The simple linear correlation was performed in $F_2$ and $F_3$ generations for single plant yield with twelve traits (Table 2; Fig. 3). The results of $F_2$ correlation showed that the single plant yield was significantly positively correlated with plant height ($r = 0.852$, $r_{0.01} = 0.683$), number of tiller ($r = 0.860$, $r_{0.01} = 0.683$), number of productive tillers ($r = 0.877$, $r_{0.01} = 0.683$), flag leaf length ($r = 0.691$, $r_{0.01} = 0.683$), flag leaf width ($r = 0.620$, $r_{0.05} = 0.552$), panicle length ($r = 0.869$, $r_{0.01} = 0.683$), wet biomass ($r = 0.909$, $r_{0.01} = 0.683$) and dry matter produced ($r = 0.947$, $r_{0.01} = 0.641$). Third leaf breadth showed significant negative correlation with grain yield. In $F_3$, the tiller per plant had significant positive correlation with grain yield wet biomass ($r = 0.567$, $r_{0.05} = 0.552$), dry matter produced ($r = 0.605$, $r_{0.05} = 0.552$) and harvest index ($r = 0.644$, $r_{0.05} = 0.552$) (Table 3; Fig. 3). Based on correlation analysis in $F_2$ and $F_3$, it was observed that the key contributor for grain yield was dry matter produced and wet biomass. This showed that the mutant N22-CC-M4-HT-1333 selected for altered biomass contributing grain yield was efficient. Among all the traits, wet biomass and dry matter produced showed highest correlation coefficient showing strong correlation of trait with dry matter produced with grain yield. This was supported by Wu et al. (2008) where they studied the correlation of grain yield with dry matter accumulation at different growth stages of super hybrid rice. They found that the biomass yield was key in improvement of super hybrid rice rather than harvest index. Bueno and Lafarge (2009) reported that the biomass accumulation and harvest index were significantly correlated to grain yield. Chen et al. (2012) found that grain per m$^2$ quadratically correlated with stem dry matter at heading stage and suggested that the dry matter accumulation during heading was more contributing for grain yield and dry matter produced prior to heading may have negative effect. Plant height was reported to have positive correlation with biomass in Indica hybrids by Li et al. (2019). Yield improvement can be done by increasing harvest index by reducing plant height especially in semi dwarf rice varieties (Khush, 1999). In this study, even though plant height showed significant correlation with grain yield, dry matter produced, number of tillers and productive tillers in $F_2$ generation, it showed no significance correlation with grain yield, dry matter...
produced, number of tillers and productive tillers in F$_3$ generation. Lakshmi et al. (2014), Kishore et al. (2015) and Kahani and Hittalmani (2016) have reported significant positive correlation of number of productive tillers, panicle length, and plant height.

Fig. 3. Heatmap of correlation coefficient in N22 x N22-CC-M4-HT-1333 of a. F$_2$ generation; b. F$_3$ generation
Grain yield is a complex trait governed by quantitative trait loci and environmentally influenced (Wang et al., 2012, Zeng et al., 2017 and Li et al., 2019). In rice, yield increase is explored in many ways for crop improvement. Ideotype breeding by altering plant architecture is an established strategy for yield improvement (Jeon et al., 2011). Based on this study, it was found that the mutant parent N22-CC-M4-HT-1333 was efficient parent in increasing grain yield through altered biomass and dry matter production. Upon exploring the genomic regions contributing for altered plant type, it can be concluded that the key factor for increasing grain yield is increase in biomass production. This mutant parent is good source for studying functional genomics of altered plant architecture, biomass production and grain yield to serve in future breeding programs.

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Table 3. Correlation coefficient in F$_1$ generation of population of N22 x N22-CC-M4-HT-1333

|   | PH | NT | NPT | FLL | FLW | PnL | TLL | TLB | TLW | WB | DMP | HI | GY |
|---|----|----|-----|-----|-----|-----|-----|-----|-----|----|-----|----|----|
| PH | 1.000 |     |      |     |     |     |     |     |     |     |     |    |    |
| NT | -0.151 | 1.000 |      |     |     |     |     |     |     |     |     |    |    |
| NPT | 0.061 | 0.506 | 1.000 |     |     |     |     |     |     |     |     |    |    |
| FLL | 0.467 | -0.243 | -0.136 | 1.000 |     |     |     |     |     |     |     |    |    |
| FLW | 0.213 | -0.053 | -0.008 | 0.436 | 1.000 |     |     |     |     |     |     |    |    |
| PnL | 0.384 | -0.254 | -0.150 | 0.539 | 0.290 | 1.000 |     |     |     |     |     |    |    |
| TLL | 0.071 | -0.044 | 0.085 | 0.038 | 0.039 | 0.058 | 1.000 |     |     |     |     |    |    |
| TLB | 0.029 | -0.095 | -0.013 | 0.062 | 0.170 | 0.117 | 0.557 | 1.000 |     |     |     |    |    |
| TLW | -0.015 | -0.063 | 0.040 | 0.007 | 0.040 | 0.058 | 0.884** | 0.709** | 1.000 |     |     |    |    |
| WB | 0.280 | 0.426 | 0.453 | 0.063 | 0.087 | 0.028 | -0.028 | -0.106 | -0.063 | 1.000 |     |    |    |
| DMP | 0.314 | 0.405 | 0.453 | 0.100 | 0.093 | 0.063 | -0.001 | -0.093 | -0.045 | 0.876** | 1.000 |    |    |
| HI | 0.168 | -0.187 | -0.127 | 0.224 | 0.096 | 0.235 | -0.016 | 0.018 | -0.005 | -0.019 | -0.087 | 1.000 |    |    |
| GY | 0.390 | 0.096 | 0.183 | 0.245 | 0.130 | 0.244 | 0.015 | -0.038 | -0.018 | 0.567* | 0.805* | 0.644* | 1.000 |

\[ *r_{0.05} = 0.552, **r_{0.01} = 0.683 \]
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