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GENOTYPE BY ENVIRONMENT INTERACTION AND GENOTYPE STABILITY ANALYSES ON ADVANCED FRAGRANT RICE LINES DERIVED FROM MR269 × BASMATI 370

NORAINY BINTI MD HASHIM

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By

NORAINY BINTI MD HASHIM

Thesis Submitted to the School of Graduated Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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DEDICATION

This thesis is dedicated to my parents for their encouragements, love and supports throughout my studies.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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Chairman: Prof. Mohd Rafii Yusop, PhD
Institute: Tropical Agriculture and Food Security

Aromatic or fragrant rice is special rice sold at a premium price in local and export markets because of their superior grain qualities. The uniqueness of this rice plays a major role in its marketability or consumer acceptability. In this research, 40 advanced fragrant rice genotypes were evaluated at two locations in two planting seasons, namely Tanjung Karang, Selangor and Kota Sarang Semut, Kedah. The main objectives were to identify genotypes with high grain yield performance and high stability using univariate and multivariate analysis (AMMI and GGE biplot method). The field experiment was conducted in a randomized complete block design (RCBD) with three replications. The morphological and agronomical were taken during growing and harvesting stages. The analysis of variance showed highly significant differences among genotypes, environments, replications, and present of genotype by environment interactions for plant height, effective tillers, yield per plant, yield per hectare, total milling rice, milled rice length, milled rice width, and milled rice length-to-width ratio. However, the other traits such as total tillers, total spikelets per panicle, filled grains per panicle, percentage of filled grain per panicle, percentage of unfilled grain per panicle, head rice recovery, and gel consistency showed significant presence of genotype by environment interaction. Phenotypic correlation shows that yield per plant has same result with yield per hectare which is significantly correlated with number of total tillers per plant, number of effective tillers per plant, total number of spikelet per plant, filled grain per panicle, percentage of filled grain per panicle, yield per hectare (1.00), brown rice, total milling rice, head rice recovery, milled rice length, milled rice width, gel consistency, and amylose contain traits. High correlation between two characters indicated that selection for the improvement of one character leads to the simultaneous improvement in the other character. High heritability values were observed for days of flowering (95.51%) and days of maturity traits (97.02%). While moderate heritability values were observed for plant height (58.19%), rice kernel elongation (50%) and aroma (49.59%) traits. For univariate analysis, Linear regression of coefficient *bi* deviation of yield trait the results showed there is no

genotypes have unity value for $\boldsymbol{bi}$. For Kang stability analysis, the top six genotypes with highest yield per hectare and ($\boldsymbol{YSi}$) across the entire four environments are G40 (control), G25, G8, G1, G21 and G11 respectively. Multivariate analysis GGE Biplot show the yield performance of the genotypes fluctuated across environments. The three genotypes were selected having the highest grain yield mean, namely G1 (7.83 t ha^{-1}), G22 (7.15 t ha^{-1}), and G25 (7.13 t ha^{-1}), across the environments. The AMMI analysis results showed that genotype G1 and G14 were the best genotypes at Kedah or Kota Sarang Semut due to its highly stable and high yielding for both planting seasons. The selected fragrant rice genotypes G1 (7.83 t ha^{-1}), G14 (6.74 t ha^{-1}), G22 (7.15 t ha^{-1}) and G25 (7.13 t ha^{-1}) are recommended for large scale evalution and then for the commercial cultivation in Malaysia.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

INTERAKSI GENOTIP DENGAN PERSEKITARAN DAN ANALISIS KESTABILAN GENOTIP PADA TITISAN MAJU PADI WANGI BERASAL DARI MR269 × BASMATI 370

Oleh

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Beras aromatik atau wangi adalah beras istimewa yang dijual pada harga premium di pasaran tempatan dan eksport kerana kualiti bijirinnya yang unggul. Keunikan beras ini memainkan peranan yang utama dalam keboleh pasaran atau penerimaan oleh pengguna. Dalam kajian ini, 40 genotip padi wangi telah dinilai di dua lokasi pada dua musim penanaman iaitu Tanjung Karang, Selangor dan Kota Sarang Semut, Kedah. Objektif utama adalah untuk mengenalpasti genotip yang berprestasi hasil bijian dan kestabilan yang tinggi dengan menggunakan analisa univariate dan multivariate (kaedah AMMI dan dwiplot GGE). Eksperimen di lapangan telah dijalankan menggunakan rekabentuk blok penuh terawak (RCBD) dengan tiga replikasi. Data morfologi dan agronomik telah dicerap semasa peringkat pertumbuhan dan penuaian. Analisa varians telah menunjukkan perbezaan yang ketara antara genotip, persekitaran, replikasi serta wujud interaksi genotip dengan persekitaran untuk ciri ketinggian pokok, anak pokok efektif, hasil sepokok, hasil sehektar, jumlah beras, panjang beras, lebar beras dan nisbah panjang ke lebar beras. Walau bagaimanapun, ciri-ciri lain seperti jumlah anak pokok, jumlah spikelet setangkai, peratus bijian berisi setangkai, peratusan bijirin berisi setangkai, peratusan bijirin tidak berisi setangkai, pemulihan kepala beras, dan konsistensi gel menunjukkan kewujudan ketara interaksi genotip dengan persekitaran. Kolerasi fenotip menunjukkan berat per pokok mempunyai keputusan yang sama dengan berat per hektar di mana signifikasi positif terhadap nombor keseluruhan tangkai padi, nombor keseluruhan tangkai padi yang aktif, peratus biji padi bernas, jumlah spikelet per pokok, peratus biji padi bernas, berat sehektar, beras peras, jumlah beras putih, pemulihan kepala beras, panjang beras, lebar beras, konsistensi gel, dan nilai amilosa. Kolerasi yang tinggi antara dua karakter bermaksud pemilihan untuk perbaiki karakter tersebut menyumbang sebaliknya pada karakter yang kolerasi positif. Nilai heritabiliti yang tinggi didapati untuk bilangan hari berbunga (95.51%) dan bilangan hari kematangan (97.02%). Manakala, nilai heritabiliti sederhana untuk ciri ketinggian pokok (58.19%), pemanjangan isirong nasi (50%) dan aroma (49.59%). Untuk univariat analisis, regrasi linear *bi* untuk karakter hasil menunjukkan tiada keputusan yang

mempunyai nilai 0. Analisis stabiliti Kang pula menunjukkan enam genotip dengan hasil paling berat ialah G40, G25, G8, G1, G21 dan G11 yang merentasi keempat-empat persekitaran. Multivariat analisis GGE biplot pula menunjukkan prestasi hasil genotip berubah-ubah mengikut persekitaran tersebut. Tiga genotip telah dipilih berdasarkan purata hasil bijian tertinggi dari semua persekitran iaitu G1 (7.83 t ha^{-1}), G22 (7.15 t ha^{-1}) dan G25 (7.13 t ha^{-1}). Keputusan analisa AMMI menunjukkan bahawa genotip G1 dan G14 adalah genotip terbaik di kawasan Kedah atau Kota Sarang Semut kerana kestabilannya serta berhasil tinggi untuk kedua-dua musim penanaman. Genotip padi wangi terpilih ini G1 (7.83 t ha^{-1}), G14 (6.74 t ha^{-1}), G22 (7.15 t ha^{-1}) dan G25 (7.13 t ha^{-1}) adalah disyorkan untuk penilaian berskala besar dan seterusnya untuk penanaman secara komersial di Malaysia.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- The research conducted and the writing of this thesis was under our supervision,
- Supervision responsibilities as slated in Rule 41 in Rules 2003 (Revision 2012-2013) were adhered to.

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LIST OF ABBREVIATIONS

AC	Amylose content
AEC	Average environment coordinate
AMMI	Additive main effect and multiplicative interaction effect;
ANOVA	Analysis of variance
ARM	Aroma sensory test
ASV	Alkaline Spreading Value
BC_2F_2	Second filial of second backcross generation
CV	Coefficient of variation
DAP	Days after planting
DF	Days to flowering
DM	Days to maturity
EMS	Expected mean square
ET	Effective tiller per plant
FAO	Food agriculture organization
FGP	Filled grain per panicle
GA	Genetic advance
GC	Gel consistency
GCV	Genotypic variance
G×E	Genotype × environmental interaction
GGE	Genotype main effects plus genotype × environmental interaction model
GT	Gelatinization temperature
HRR	Head rice recovery
HSD	Honest Significant Different

IPC	Interaction principal components
IRRI	International Rice Research Institute
KE	Kernel elongation
KOH	Potassium hydroxide
LSD	Least significant difference
MARDI	Malaysian Agriculture Research and Development Institute
MADA	Muda Agriculture Development authority
MABC	Marker assisted backcrossing
MLWR	Milled rice length to width ratio
MM	Kedah main season
MO	Kedah off season
MOP	Muriate of potash
MRL	Milled rice length
MRW	Milled rice width
NaOH	Sodium hydroxide
NGO	Non-Governmental Organization
NKEA	National key Economic Area
PC	Principal Component
PC1	Principle component 1
PC2	Principal component 2
PH	Plant height
PL	Panicle length
QTL	Quantitative trait loci
RCBD	Randomized complete block design
SAS	Statistical analysis software

SASG×E	SAS genotype × environmental interaction analysis program
SVD	Singular value decomposition
SVP	Singular value partition
TGW	1000-grain weight
TKM	Tanjung Karang main season
TKO	Tanjung Karang off season
TMR	Total milling rice
TSP	Total spikelets per panicle
TT	Total number of tillers
UGP	Unfilled grain per panicle
Yha	Yield per hectare
YP	Yield per plant

CHAPTER 1

INTRODUCTION

1.1 Background

Rice is an important staple food that nourishes more than half of the world's population. It was classified as a second-most main crop in the world and Asia is the largest producer and consumer (Gumma *et al.,* 2011). In Malaysia, The National Agrofood Policy 2011-2020 of Malaysia launched by Ministry of Agriculture and Agro-based Industry in 2010 had stated that local rice production should be increased to cater the national food security. In order to increase rice production in Malaysia, the government policies have focus on encouraging the local rice production and lowering dependency on imported rice to give benefit to Malaysia rice industry (Rajamoorthy *et al*., 2015).

Aromatic rice is a very famous rice variety and has been introduced into the global market. Additionally, fragrance rice also is a key factor in determining the market price at RM 4.50 per kg or more in Malaysia on 2019 (MARDI, 2012). The chemical compound present in the plants which resulting a fragrance smell provides a premium price in the market. A new blueprint for strategy and priority 2019-2020 launched by Ministry of Agriculture and Agro-based Industry had highlighted the expansion the cultivation of fragrant rice in the granary and non-granary area in Malaysia (MOA., 2019).

Development of a new fragrant rice variety by introgression of the fragrance gene, into high yielding variety is very crucial due to higher demand and price in the local market. Lack of high yielding fragrant rice variety in Malaysia is one of the major hindrances on fragrant rice production in Malaysia. Two fragrant rice variety has been released by MARDI namely, MRQ 74 and MRQ 76. (Shahida *et al.*, 2016). These varieties have been widely cultivated in the granary and non-granary areas in Malaysia.

For rice quality, the aromatic trait is one of the quality used in rice classification. Aromatic rice was lack in the global market. This type of rice was trade from India, Pakistan, and Thailand. Aromatic rice from India and Pakistan consists of Basmati types, while Jasmine rice is commonly produced in Thailand. Other important aromatic varieties in the world market include Khao Dawk Mali 105, Siamati (Thailand), Bahra (Afganistan), Sadri (Iran), Della, Texami and Kasmati (USA) (Singh *et al*., 2000). Aromatic or scented rice typically accounts for only 15% of total world trade, but exceeded 5.7 million tons in 2010.

Due to high demand of aromatic rice, plant breeder has employed different approaches in the development of advance rice variety using both conventional and molecular methods. The molecular introgession of the fragrance gene has been widely used with numerous sucessful stories. However, the advanced line produce needs to undergo multi location yield trial, in order to determine the best and stable rice genotype adapted in the granary area under different environment.

Yield stability of the advanced lines was response from the genotype × environment interaction (G×E). Understanding the G×E interaction is important in plant breeding programs and has been a major key in selection of the potential advanced lines or genotypes for future development or release as new variety. Generally, genotypes responsed differently in diverse environment due to the influence of environmental conditions. Inbred or hybrid rice varieties will produce different responses as changing the environmental conditions, these varieties may not produce uniform yield and other traits as the result of segregation and the presence of genotype × environment interaction.(Satoto *et al*., 2010; Sreedhar *et al.,* 2011; Widyastuti et al., 2012; Satoto *et al.,* 2013)

In this study, the advanced fragrant rice lines developed from the cross between MR269 and Basmati370 was used to evaluate in two different granary areas at two season to determine the genotype yield stability. Similarly, lines which produce stable high aromatic smell and grain quality across environments were also considered.

1.2 Significance of study

The continuous increase in demand for aromatic rice justifies the need for development of high yielding fragrant rice variety to increase the current low yield output. However, the developed advance rice line must be evaluated in multi-location yield trial to select genotype with high yield, fragrant and stability. This is so because: (i). Yield stability performance differs across environments (ii). The phenotypic response in different environment is not the same for all the genotypes leading to G×E interaction (iii). Released varieties differ in adaptation and consistency performance in yield across the various environments. Therefore, it is great opportunity to identify genotype with high stable yield and grain quality (fragrant trait) that is well adapted to a wide range of environment suitable to Malaysia. This advanced lines also will added into genetic diversity of fragrant rice variety in Malaysia.

1.3 Problem Statement

As Malaysia is determined to reduce her dependency on rice importation from other countries, couple with the demand for aromatic rice, the development of stable and high yielding aromatic rice varieties for local cultivation is of prime important for enhancing self-sufficiency's and compacting climatic changes. Aromatic rice is special rice sold at a premium price in local and export markets because of their superior grain qualities (Sakthivel *et al.*, 2009). As stated by FAO, (2012), the priced of fragrant rice rise up to USD $1,050/T (RM 4.50/kg) as compared with USD $440-580/T (RM 1.80/kg – RM 2.40/kg) of coarse rice and in Malaysia priced for fragrant rice. Because fragrant varieties have low yield, farmers stopped growing specific local fragrant varieties and replaced them with the new, fast growing, disease resistant, high yielding, non-fragrant varieties (Bhattacharjee *et al.*, 2002; Itani *et al*., 2004). Recently, the local fragrant rice developed by MARDI are MRQ74 and MRQ76. The disadvantaged is that the yield of these varieties are lower than the local high yielding varieties. Increasing the yield of fragrant rice in other to reduce the cost of importation from others countries, the rice breeding program was fashioned towards development of high yielding fragrant rice varieties. Consequently, stability analysis is often part of the performance evaluation of genotypes prior to cultivar release. Thus, to ensure the stability of BC_2F_2, the evaluation of genotypes for stability of yield performance under varying environmental conditions should be carried out.

1.4 Objectives

The objectives of this experiment were:

i) To evaluate the advanced fragrant rice lines for yield, grain quality, growth and aromatic traits in different locations and different seasons.

ii) To estimate genetic variance and heritability values of the rice population

iii) To identify genotypes with high stability and adaptability across different environments.

REFERENCES

Ahmad Hanis, I.A.H., Jinap, S., Mad Nasir, S., Alias, R. and Muhammad Shahrim, A.K. (2012). Consumers' demand and willingness to pay for rice attributes in Malaysia. *International Food Research Journal* 19(1): 363-369.

Ali, S.S., Jafri S.J.H., Khan, T.Z., Mahmood, A. and Butt, M.A. (2000). Heritability of yield and yield components of rice. *Pakistan Journal of Agricultural Research* 16: 89-91.

Asante, M. 2017. Advances in International Rice Research. *Breeding Rice for Improved Grain Quality* (pp. 70-80). Intech Publisher. Kumasi, Ghana.

Assefa, K., Ketema, S., Tefera, H., Nguyen, H.T., Blum, A., Ayele, M., and Kefyalew, T. (1999). Diversity among germplasm lines of the Ethiopian cereal tef [*Eragrostis tef* (Zucc.) Trotter]. *Euphytica* 106: 87–97.

Azer, S. A. and Ibrahim, K. I. M. (2003). Genotype x environment interaction and phenotypic stability for grain yield and its attributes in some promising rice mutant lines. *Annals of Agricultural Science* Cairo 48(1) : 159-172.

Bagheri, N.A., Babaeian-Jelodar, N.A., and Pasha, A.(2011). Path coefficient analysis for yield and yield components in diverse rice (*Oryza sativa L.*) genotypes. *Biharean Biologist* 5(1): 32-35.

Becker, H.C., and Leon, J. (1988). Stability analysis in plant breeding. *Plant Breeding*. 101: 1–23.

Beras Wangi Import. https://blogmardi.wordpress.com/tag/beras-wangi-import/ (2012). (accessed on 15 December 2018).

Bhattacharjee P, Singhal RS, and Kulkarni PR (2002). *Basmati rice: A review. International Journal Food Science Technology* 37:1–12.

Bisne, R., Sarawgi, A., & Verulkar, S. (2009). Study of heritability, genetic advance and variability for yield contributing characters in rice. *Bangladesh Journal of Agricultural Research 34*(2), 175-179.

Bhakta, N. and Das, S. R. (2008). Phenotypic stability for grain yield in rice. *Oryza*, 45 (1) :115-119.

Bhutta, W.M. (2006). Role of some agronomic traits for grain yield production in wheat (*Triticum aestivum L.*) genotypes under drought conditions. *Revista UDO Agricola* 6: 11-19.

Brar, B., Jain, S., Singh, R. and Jain, R.K. (2011). Genetic diversity for iron and zinc contents in a collection of 220 rice (*Oryza sativa L.*) genotypes. *Indian Journal of Genetics and Plant Breeding* 71(1):67-73.

Chang, T.T., and Bardenas, E.A. (1965). The morphology and varietal characteristics of the rice plant. *Technical Bulletin 4*. pp. 40. IRRI: Philippines.

Crossa, J. (1990). Statistical Analyses of Multilocation Trials. *Advances in Agronomy* 44:55-85.

CRAN. (2014). The comprehensive R archive network. Comprehensive R Archive Network for the R programming language. http://cran.r project.org/web/packages/available_packages_by name.html#available packages–A (accessed 1 December, 2016).

Dia, M., Wehner, T.C., and Arellano C. (2015). Analysis of genotype x environment interaction (G×E) using SAS programming. http://cuke.hort.ncsu. edu/cucurbit/wehner/software.html (accessed 15 August . 2018).

Eberhart, S.A. and Russell, W.A. (1966) Stability parameters for comparing varieties. *Crop Science*. 36–40.

ETP (2010). Introducing fragrant rice variety for non-irrigated areas. http://www.etp.pemandu.gov.my. (accessed on 15 December 2018).

F. S. Golestan Hashemi, M. Y. Rafii, M. R. Ismail, T. M. M. Mahmud, H. A. Rahim, R. Asfaliza, M. A. Malek and M. A. Latif (2013) Biochemical, Genetic and Molecular Advances of Fragrance Characteristics in Rice, *Critical Reviews in Plant Sciences*, 32:6, 445-457,

FAO. 2012. Rice Market Monitor. XV (4): November 37.

Falconer, D. S. (1975). Introduction to quantitative genetics. Pearson Education India.

Fehr, W.R. 1987. *Principles of Cultivar Development. Vol.1. Theory and Technique.* Collier Macmillan Publishers, London. 249-259.

Finlay, K.W. and Wilkinson, G.N. (1963) The analysis of adaptation in a plant breeding programme. *Australian Journal of Agricultural Research* 14: 742–754.

Fowler, C. and Mooney, P. 1990. Shattering: Food, Politics and Loss of Genetic diversity. University of Arizona Press. Tucson

Gannamani, N. 2001. *Study of heterosis and combining ability by utilizing cytoplasmic genetic male sterility and fertility restoration system in rice* (*Oryza sativa L.*, M. Sc. (Ag.) Thesis, GAU, Raipur.

Gauch, H.G., Jr (1992) Statistical Analysis of Regional Yield Trials: AMMI Analysis of Factorial Designs. *Elsevier,Amsterdam,The Netherlands*.

Giraud, G. (2013). The world market of fragrant rice, main issues, and perspectives. *International Food and Agribusiness Management Review.* 16(2):1-20.

Gramene 2016: comparative plant genomics and pathway resources. http://www.gramene.org (a accessed 15 August . 2018)

Gumma, M., Nelson, A., Thenkabail, P., and Singh, A. (2011). Mapping rice areas of South Asia using MODIS multitemporal data. *Journal of Applied Remote Sensing*. 5. 053547.

Haryanto, T.A.D., Suwarto, and Yoshida, T. (2008). Yield Stability of Aromatic Upland Rice with High Yielding Ability in Indonesia. *Plant Production Science* 11(1):96-103.

Hasan, M.J., Kulsum, M.U., Akter, A., Masuduzzaman, A.S.M., and Ramesha, M.S. (2013). Genetic variability and character association for agronomic traits in hybrid rice (Oryza sativa L.). *Bangladesh Journal Plant Breeding Genetics* 24(1): 45-51.

Hill, J. (1975). Genotype-environment interaction-a challenge to plant breeding. *Journal of Agricultural Science.*(Cambridge) 85:477-499.

Itani, T., Tamaki, M., Hayata, Y., Fushimi, T., and Hashizume, K. (2004). Variation of 2Acetyl1Pyrroline Concentration in Aromatic Rice Grains Collected in the Same Region in Japan and Factors Affecting Its Concentration. *Plant Production Science* - Plant Prod Sci. 7. 178-183. 10.1626/pps.7.178.

Jamal, K., Kamarulzaman, N.H., Abdullah, A.M., Ismail M.M. and Hashim, M. (2014). Adoption of fragrant rice farming: The case of paddy farmers in the East Coast Malaysia. *UMK Procedia* 1:8-17.

Japan International Coorperation Agency (JICA). Rice Post Harvest Technology Program. Ministry of Agriculture, Animal Wealth and Natural Resources. *Rice Promotion Unit*-December 2013.

Johnson, H.W., Robinson, H.F., and Comstock, R.E. (1955). Estimates of genetic and environmental variability in soybeans. *Agronomy Journal*, 47: 314−318.

Juliano, B.O and Perez,G.S. (1984*). Some grain properties of IR36-based starch mutants. Starch*, 42: 256-260

Juliano, B.O., and Villareal, C.P. (1993). Grain quality evaluation of world rices. Los Banos: *International Rice Research Institute (IRRI).*

Kang, M.S. (2004). Breeding: Genotype-by-Environment Interaction. *In Encyclopedia of Plant and Crop Science*. pp. 218–221. Kumasi, Ghana.

Kang, M.S., and Pham, H.N. (1991). Simultaneous selection for high yielding and stable crop genotypes. *Agronomy Journal* 83: 161–165.

Kang, M. S. (2002). Genotype-environment interaction: progress and prospects. *Quantitative Genetics, Genomics and Plant Breeding* 221–243.

Lai, J., Dey, N. and Kim, C.S. (2004). Characterization of the maize endosperm transcriptome and its comparison to the rice genome. *Genome Research*. 14: 1932-1937.

Lau, W. C. P., Yusop, M. R., Ismail, M. R., Puteh, A., Latif, M. A., Asfaliza, R., and Miah, G. (2017) Development of advanced fragrant rice lines from MR269 × Basmati 370 through marker-assisted backcrossing. *Euphytica*, 213 (11). pp. 1-15.

Lin, M.S. (1991). Genetic base of Ja nica rice varieties rel in Taiwan . *Euphytica* 56: 43.

MOA (2019) - Ministry of Agriculture and Agro-based Industry Malaysia. Hala Tuju Kementerian Pertanian dan Industri Asas Tani Prioriti dan Strategi 2019-2020. Putrajaya.

Maxwell Darko Asante (2017). Breeding Rice for Improved Grain Quality, *Advances in International Rice Research*, Jinquan Li, IntechOpen.

Nguyen Loc Hien, Tadashi Yoshihashi, Wakil Ahmad Sarhadi and Yutaka Hirata (2006) Sensory Test for Aroma and Quantitative Analysis of 2-Acetyl-1-Pyrroline in Asian Aromatic Rice Varieties, *Plant Production Science*, 9:3, 294-297

Oladosu, Y. Rafii, M.Y., Abdullah, N. ., Magaji, U., Miah, G., Husin, G. and Ramli, A. (2017). Genotype x environment interaction and stability analyses of yield and yield components of established and mutant rice genotypes tested in multiple locations in Malaysia. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*.

Pattanaik,S., A. Paul and P. C. Lenka. (2015). Genotypic and phenotypic variability and correlation studies in gladiolus. *Journal Crop and Weed*, 11(1):113-119

Perangkaan Agromakanan 2015 (2015). http://www.data.gov.my/data/ms_MY/dataset/perangkaan-agromakanan-2015. Accessed on 10 December 2018.

Rajamoorthy, Y., Abdul Rahim, K. and Munusamy, S. (2015). Rice Industry in Malaysia: Challenges, policies and Implications. *Procedia Economics and Finance*. 861-867.

Rathnathunga, udari, Senanayake, S. G. J. N., Dissanayake, N., Seneweera, Saman and Geekiyanage, Sudarshanee. (2016). Vegetative growth and yield Associated Flowering Time Variation in Sri Lankan Rice "Hondarawala". *Journal of Agricultural Sciences*. 11.

Rebeira, S.P., Wickramasinghe, H.A.M., Samarasinghe, W.L.G. and Prashantha, B.D.R. (2014). *Diversity of grain quality characteristics of traditional rice* (*Oryza sativa* L.) varieties in Sri Lanka.

Romagosa, I. and Fox. P.N. (1993). Genotype × environment interaction and adaptation. *Plant Breeding*. 373-390.

RStudio. (2014). RStudio: Integrated development environment for R (Computer software v0.98.1074). RStudio. http://www.rstudio.org/ (accessed 8, 2018).

Sadeghi, S.M., (2011). Heretability, Phenotypic correlation and path coefficient studies for some agronomic characters in Landrace rice varieties. *World Appled Sciences Journal*, 13(5): 1229- 1233.

Sao, A. (2002). *Studies on combining ability and heterosis in F1 rice hybrids using cytoplasmic male sterile lines*. M. Sc. (Ag.) Thesis, IGAU, Raipur.

Satoto, M.J. Mejaya, Y. Widyastuti and I.A. Rumanti. (2013). Yield Stability of New Hybrid Rice Varieties (in Indonesian). *Jurnal Penelitian Pertanian Tanaman Pangan* 32(2):67.73.

Satoto, Y. Widyastuti, I.A. Rumanti and T.W.U. Sudibyo. (2010). Yield stability and resistance to bacterial leaf blight and tungro of hybrid rice varieties Hipa 7 and Hipa 8 (in Indonesian). *Jurnal Penelitian Pertanian Tanaman Pangan*. 29(3): 129-135.

Sakthivel, K., Sundaram, R.M., Shobha Rani, N., Balachandran, S.M. and Neeraja, C.N. (2009).Genetic and molecular basis of fragrance in rice. *Biotechnology Advances* 27:468–473

Satheesh Kumar, P. and Saravanan, K. (2012). Genetic variability, correlation and path analysis in rice (Oryza Sativa L.). *International Journal of Current Research*. Vol. 4(09): 082-085.

Sarawgi, A. K., N. K. Rastogi, and D. K. Soni. (2000). Studies on some quality parameters of indigenous rice in Madhya Pradesh. *Annual Agriculture Resource*. 21(2): 258 261.

Seedek, S.E.M., Hammoud, S.A.A, Ammar, M.H. and Metwally, T.F. (2009). Genetic Variability, Heritability, Genetic Advance Andd Cluster Analysis for Some Physiological, Traits, and Grain Yield And Its Components in Rice (*Oryza sativa* L.). *Journal of Agriculture Resource*. 35: 858-877.

Singh, R.K., & Chaudhary, B.D. (1977). Biometrical methods in quantitative genetic analysis. Kalyani Publishers, Ludhiana, New Dehli, India.

Sinha, A., and K Kumar, P., and Mishra, P. K. (2013). Agronomic Evalution Of Landraces Of Rice (Oryza Sativa) Of Bankura District Of West Bengal. *International Journal of Innovations in Bio-Sciences*. 3. 27-32.

Shahida, H., Siti Norsuha M., Nur Khairani, A.B., Mohamad Najib, M.Y., Muhammad Naim Fadzli, M.R., Asfaliza, R., and Shajarutulwardah, M.Y. (2016). Effect of Organic Fertiliser as a Basal Fertiliser on Growth, Disease Incidence of Local Fragrant Rice Varieties. *Journal of Tropical Agriculture and Food Science* 44(2):167-178.

Singh, R.K., Singh, U. S., and Khush, G. S. (2000). Prologue. In: R. K. Singh, U. S. Singh & G. S. Khush (Eds.), *Aromatic rices* (pp. 1-4). New Delhi: Oxford and IBH Publishing Co. Pvt. Ltd.

Sivasubramanian, S., & Madhavamenon, P. (1973). Genotypic and phenotypic variability in rice. *Madras Agricultural Journal 60:* 1093−1096.

Sreedhar, S., T.D. Reddy and M.S. Ramesha. (2011). Genotype x environment inter action and stability for yield and its components in hybrid rice cultivars (*Oryza* *sativa* L.). *International Journal of Plant Breeding and Genetics.* 5(3): 194 208.

Srivastava, J.P. and Jaffe, S.1993. Best practices for Moving Seed Technology: New Approaches to doing Business. *World Bank Technical Paper* No-213. The World Bank. Washington, DC.

Surek, H. and Beser, N. (2003). Selection for grain yield and yield components in early generations for temperate rice. *Philippine Journal of Crop Science.* 28: 3-15.

Unnevehr, L.J., Duff, B. and Juliano, B.O. (1992). Consumer demand for rice grain quality. *International Rice Research Institute (IRRI).*

Vivekanandan , P. and Subramanian, M. (1994). Stability analysis in rainfed rice *Oryza sativa* L. Oryza, 31: 224-225.

Widyastuti, Y. and Satoto. (2012). Yield stability and adaptability of five hybrids rice at Central Java (in Indonesian). *Jurnal Penelitian Pertanian Tanaman Pangan*. 31(2): 87 92.

Yan, W., & Kang, M.S. (2002). GGE biplot analysis: A graphical tool for breeders, geneticists, and agronomists. *CRC press*. New York, USA, pp. 71.

Yan, W., L.A. Hunt, Q., Sheng, and Z. Szlavnics. (2000). Cultivar Evaluation and Mega Environment Investigation Based on the GGE Biplot. *Crop Science* 40:597-605

Yan, W., Kang, M., Ma, B., Woods, S., and L. Cornelius, Paul. (2007). GGE biplot vs. AMMI analysis of genotype-by-environment data. *Crop Science* 47. 10.2135

Yates, F. and Cochran, W.G. (1938) The analysis of groups of experiments. 28:556.580.

Yu T.Q., Jiang W., Ham T.H., Chu S.H., Lestari P., Lee J.H., Kim M.K., Xu F.R., Han L., Dai L.Y. and Koh H.J. (2008). Comparison of grain quality traits between Japonica rice cultivars from Korea and Yunnan Province of China. *Journal of Crop Science and Biotechnology*. 11:135–140.

Z. K. Li., S. B. Yu., H. R. Lafitte., N. Huang., B. Courtois., S. Hittalmani., C. H. M. Vijayakumar., G. F. Liu., G. C. Wang., H. E. Shashidhar., J. Y. Zhuang., K. L. Zheng., V. P. Singh., J. S. Sidhu., S. Srivantaneeyakul. and G. S. Khush. QTL environment interactions in rice. I. Heading date and plant height. (2003). *Springer-Verlag*

Zhao, F. and Xu, S. (2012). Genotype by environment interaction of quantitative traits: a case study in barley. *G3-Genes Genom*ics Genetics. 2:779-788.