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META-ANALYSIS IN SOCIAL SCIENCE RESEARCH

N. BHUVANA¹, I. SREENIVASA RAO¹ and BHARAT S SONTAKKI²

¹Department of Agricultural Extension, College of Agriculture

Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad- 500 030

²CAR-National Academy for Agricultural Research Management, Rajendranagar, Hyderabad- 500 030

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ABSTRACT

Combining results of large number of heterogeneous studies into easily inferable aggregate measure is a challenge in social science, though of paramount importance. Policies cannot be based on results of individual studies as the inferences are limited by the scope of the study. Often the studies are based on smaller samples and restricted in terms of area coverage. Need of having a comprehensive aggregate indicator is even higher in cases where the studies give contradicting conclusions. The need for a method to synthesize results of numerous small studies into a more reliable, comprehensive statistical measure led to the development of 'meta-analysis'. The meta-analysis approaches like vote counting method, combined probability method and modern meta analysis tools helps to summarize and combine the results of research on a particular area of study, to arrive at statistically valid overall effect size. It facilitates testing hypothesis over combined sample size which is more precise and account also for heterogeneity. Meta-analysis accompanied with systematic review not only emphasize its use in policy making, but also throw light on research gaps in a particular field of study.

Key words: Meta analysis, Systematic review, Social science research, Evidence based research.

Social science is a category of academic disciplines, concerned with society and the relationships among individuals within a society. Branches of social science encompass anthropology, archaeology, communication studies, economics, history, human geography, jurisprudence, linguistics, political science, psychology, public health and sociology (Backhouse, 2010). Pertaining to agriculture, we mainly consider Agricultural extension and Agricultural economics as core social science disciplines. Social science research mainly addresses the social issues, provides insight into how science and innovation is perceived by the society and how it impacts their lives. It also helps Governments in designing and implementing policies to achieve specific objectives. Evaluation of the policies and suggesting future policies also comes under broad purview of social sciences.

Evidence Based Policy (EBP) is an approach that 'helps people make well informed decisions about policies, programmes and projects by putting the best available evidence from research at the heart of policy development and implementation (Sutcliffe and Court, 2005). Evidence based policies are defined as the theoretical constructs whereby policy's developed are based on sound scientific evidence (Sutcliffe and court, 2005). They are eminently sensible, testing a plausible

policy under conditions that should provide meaningful information about its effectiveness. The evidence for making policy, programme and practice decisions is best based on careful analyses and syntheses of multiple studies. These may be studies of the same topic such as microfinance and poverty, or across several areas of a single program, e.g. rural development.

But due to availability of heterogeneous studies, we get varied inferences. There are low sample sizes in the research studies and the studies are constrained to a region. The research results varies from region to region. The presence / absence of counterfactual makes difference in assessing the effectiveness of policies. These reasons limits in generalizing the findings of social science research. So, meta-analysis is one of the analytical tool which helps to formulate the evidence based policies.

The main objectives of meta-analysis are to summarize and integrate results from a number of individual studies, to analyze differences in the results among studies, to increase precision in estimating effects, to evaluate effects in subsets of interventions, to further investigate an issue, to identify the evidence gap and to generate new hypotheses for future studies.

The rationale to conduct meta-analysis is to improve the statistical power of analysis as well as to have precision of the estimates of treatment effect, to determine whether there is evidence in a set of primary studies supporting a particular hypothesis, to inform the policy by evidence synthesis with increased power and accuracy than what could be achieved in individual studies, to identify the evidence gap for making policy, programme and practice decisions is best based on careful analyses and syntheses of multiple studies (Borenstein *et al.*, 2009)

History of meta-analysis

Meta-analysis has its history from 17th century where Blaise Pascal, a French mathematician applied it on game of chance which is commonly used in gambling (Jingjing, 2014). There was shift in application of meta-analysis from gambling to astronomy in 18th and 19th century where Royal Gaus and Laplace, the British astronomers and mathematicians applied it in their studies (Keith O'Rourke, 2007).

Later in 1904, the first application of meta-analysis was observed in clinical studies by Karl Pearson, a British Statistician (O'Rourke, 2007). Similarly, in 1920s and 1930s, Ronald Fisher suggested experiment study conducted at Rothamsted agricultural research station to summarize the research work which compares and provides a combination of estimates for precise data availability. Later, Cochran and Yates applied the same method in medical research by Cochran and Yates to emphasize on need for randomized experiments in research area (Keith, O'Rourke 2007).

The word "Meta-Analysis" was coined by Gene Glass in 1976 which he defines as a statistical synthesis method that provides the opportunity to view the "whole picture" in a research context by combining and analysing the quantitative results of many empirical studies [Glass, 1976]. It refers to a process of integration of the results of many studies to arrive at evidence synthesis (Terri, 2012). It keeps itself unique from narrative summary of results obtained in systematic review by projecting quantitative evidence summary of research studies based on systematic review. The meta-analysis also known as overview synthesis and quantitative synthesis.

We commonly observe narrative synthesis of evidences in our research considering the pre-

formulated hypothesis for the study. Example: effect of KVK technologies on socio-economic status of farmers. In such condition, the reviews are selected based on its support to the formulated hypothesis. Though, the narrative summary provides knowledge about the status of research problem, it is always better if the reviews provide a quantitative evidences to decide upon the hypothesis consideration. Therefore, Glass (1976) defines the meta-analysis as a quantitative research synthesis that analyses the results of a set of existing analyses for concrete evidential results on problem of research.

Procedure of Meta-analysis

Meta-analysis usually conducted in two basic phases namely a) systematic review and b) analysis phase. Systematic review by itself is a unique concept to be known by researchers to identify unique studies relevant to the research problem. A team of systematic review experts from University of Toledo defines systematic review as a formal research study which follows a clear, predefines structure to find, assess and analyze studies that have all tried to answer a similar question. The systematic review to be started with the following pre-requisites viz., a) one must formulate a review question b) must have a clear inclusion and exclusion criteria which are systematically applied c) develop systematic search strategy d) select studies, screen, code and extract data and finally systematically report all eligible studies.

a) Formulate review question

During formulating review question, systematic review procedure applies PICOS [Population(s), Intervention(s), Comparison(s), Outcome(s), Study design(s)] which is specified to guide study inclusion criteria (Abigail *et al.*, 2014). For example: consider a review question - Impact of KVK technologies on socio-economic status of farmers. The framed review follows PICOS rule where 'Farmers' are the 'Population' under study, 'KVK technologies' act as 'Intervention', 'Adopters and non-adopters' of KVK technologies considered for 'Comparison', 'Learning outcome' will be 'Socio-economic status' and Study Design will be either 'Expost/Difference in difference method' etc.,

b) Develop search strategy and locate studies

When a researchers need to develop a search strategy, researchers must question themselves as

what are we looking for? Either quality papers or research works. It is important to search for wide variety of resources to capture theoretical and applied papers and multidisciplinary research. There is no boundary to search for reviews. Even the monographs, reports and journals are important for reviews. When browsing journals, one must decide on sector, subject and general journals list to be made and start with the search process. Example: Agricultural extensionists commonly will publish in extension journals, economic journals and development journals. The search process must be in the journals where they commonly publish the works. (Howard and Hugh, 2017)

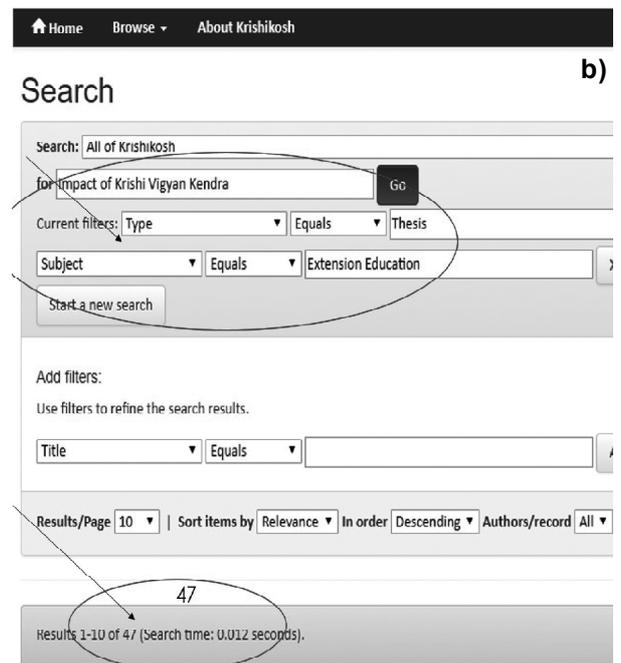
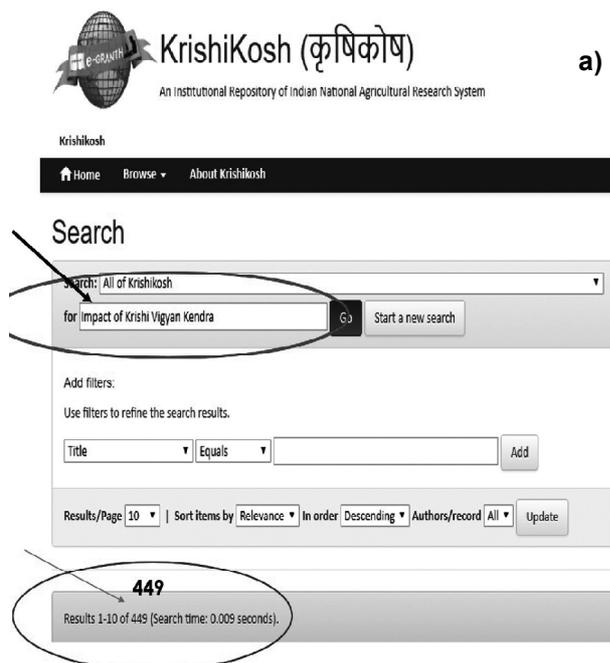
The research studies must be located from databases and registries, grey literatures, hand search, snowballing, back referencing, citation searches (eg: social sciences citation index or google scholar), contact experts in field for recent/in press/ continuing studies, document clearly final search strategies of all databases searched (Howard and Hugh, 2017). Based on the available database (google scholar, Krishi Kosh, ERIC, Agecon search etc.,) any one or two to be selected and run a search relevant to the review question formulated.

During search process, the researchers can apply Boolean operators like OR/AND/NOT in their search strategy to get more relevant results. They must apply the filters available in the databases for more precise results of your search. Consider data base

Krishi Kosh as an example where the researcher has to search the studies related to impact of *Krishi Vigyan Kendras* on farmers. Figure 1 given below provides us the glimpse of application of search strings and filters in the search process which guides us to more relevant studies and saves the time. Observe image a) under figure 1 where there is a search for studies on impact of *Krishi Vigyan Kendra* without applying any filters and the search results obtained are 449. Following, the filters are applied in image b) which has reduced the search results to 47. This indicates that only 47 studies available for our search string Impact of *Krishi Vigyan Kendra*. But, still all the 47 studies resulted are not relevant to our search string (Image c). We can see that the titles of the research studies in image c are nowhere connected to the framed search string. This indicates that, the search process must be more critical and we must apply the available options of filters in our data base for relevant results and to save time for quality search. Similarly, the search process to be continued with other possible search strings. For example: image d, with search string KVKs with application of filters, the search results obtained are 27, the researcher must critically consider these 27 studies and select the most relevant one to answer the formulated review question.

c) Data extraction and coding

The searched results are to be extracted and coded in a form called coding sheet or framework which



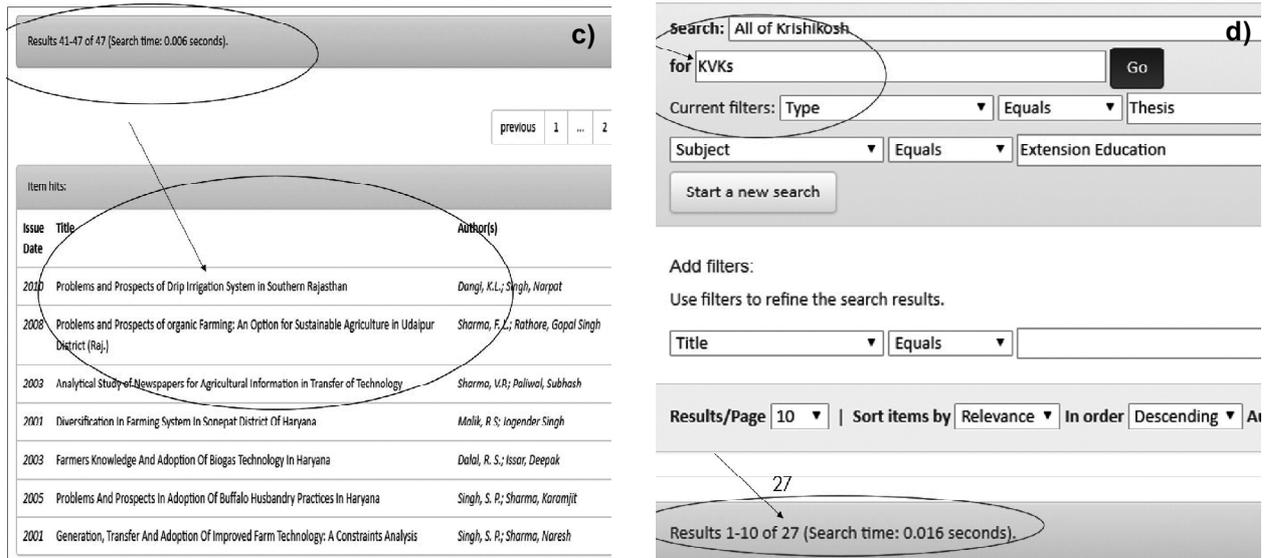


Figure 1: Glimpse of application of search strings and filters in Krishikosh data base (authors work)

will be ready for synthesis. A coding sheet encompasses ID for selected paper, papers name, country where the study conducted, region with in country if available, time and date of access of paper, year of publication, intervention used, statistical values available in the studies etc.,

d) PRISMA

(Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Figure 2 explains the PRISMA flow chart from the PRISMA statement organization which is recently adopted in all systematic reviews and meta-analysis studied. (Moher et al, 2009).

The PRISMA flow chart helps the researchers to improve the reporting of systematic reviews and

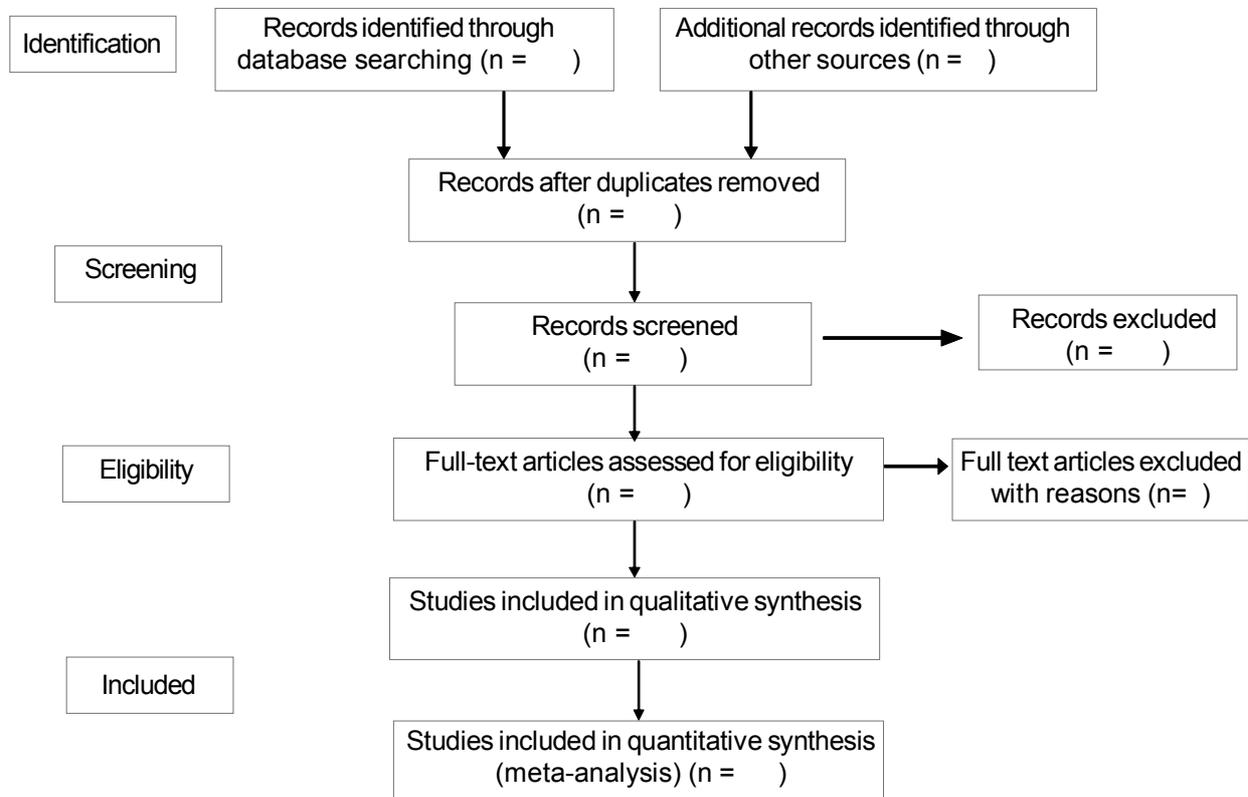


Figure 2: PRISMA Flow chart from Moher et al (2009)

meta-analysis. It filters the evidence based on PICOS. A study conducted by Klumper and Qaim (2014) applied PRISMA flow chart where he has considered a total of 24079 studies through keyword search in literature databanks like ISI web of knowledge, Econ Lit etc., Later he has screened the titles in relevance to objective of review question to consolidate the evidence of agronomic and economic impacts of GM crops and obtained a total of 24079 studies where he has excluded 21479 studies which were not meeting the inclusion criteria. Title screening was followed by abstract screening and a total 2600 studies were considered which were further subjected to full text assessment. A total of 304 studies obtained based on its eligibility to meet the objective under study. Finally, a total number of 147 unique studies were considered for meta-analysis after excluding the full text studies which were not meeting the inclusion criteria considered in the study. This indicates that PRISMA flow chart provides a critical view of studies considered for meta-analysis. But, it is not that easy as we see in flow chart - it is time consuming to search and filter the data but worth of doing to obtain quality research in the disciplines of study.

Meta-Analysis and interpretation

There are three main approaches to meta-analysis namely vote counting method, Method of combining probability and modern meta-analytic method.

In vote counting method, mainly the counts and proportions of studies are considered. The manual developed by Micheal *et al.* for meta-analysis explains that the studies which are relevant to the problem of interest are counted and tabulated. Both, significant and non-significant studies are considered and if the number of significant results are more than the number of non-significant results then the intervention or concept under study is said to be effective. It is mainly used in research summaries of social science, medical and biological sciences. But, this method is purely based on qualitative judgement and no effect size is considered. It will not consider the statistical power and heterogeneity of study.

The vote counting method is applied in the study conducted by Muhmaad *et al.* (2015) at Pakistan in the year 2015 on current status of Agricultural extension in Pakistan. The results informs that the

proportion of main research areas conducted in agricultural extension are Agricultural information source (31.7%), Public/Private extension service (26.6%), Professional competencies of Extension Field staffs (20%), Training needs assessment Extension Field Staffs (15.5%) and Agricultural extension policy (6.7%). The study also indicated the proportion of agricultural extension studies conducted region wise throughout Pakistan viz., Punjab (48.3%), Khyber Pakhtunkwa (26.7%), Sindh (16.7%), Baluchistan (1.6 %) and National level (6.7 %). The study results were able to identify the gap in agricultural extension research with respect to coverage of research areas and locale of study and suggested the researcher to conduct more policy oriented research, to focus on global issues and also proposed government to promote policy suggestions and recommendations towards sustainable agricultural and rural development.

The method of combining probabilities as an alternative to vote-counting method. (Micheal *et al.*) It mainly combines the statistical results from a set of studies based on exact probability values to provide an overall assessment of significance. The name itself indicates that combining probabilities means, it considers only the probability of each study rather than considering the distribution underlying the data. The significance of the studies are measured by effect size.

Effect size means it estimates the effect of treatment for a study. It measures the magnitude and direction of relationships between two variables or a contrast between two groups. To measure effect size, the samples considered for study must be comparable and independent of sample size.

The effect size are calculated based on the data available from primary studies. The data are calculated based on means, sample sizes and standard deviations for experimental and control groups as applied in study conducted by Alliso *et al.* (2009) to examine the gender differences in 10 specific domains of self-esteem. The researcher considered 115 studies with 32486 participants and found the effect size using Hedges- Becker formula which corrects the bias in the estimation of population effect size (refer paper for details). The results of the study indicated that the gender differences in specific domains are considerably larger compared to global self-esteem with an effect size of 0.15. This led the researcher to conclude the meta results

as the difference reflect actual gender differences in competence and performance and also not from actual deficits but also from more critical reflected appraisals of others including idealized media images.

The effect size which are core part of meta-analysis is also measure by applying odds ratio (OR) and Risk ratios (RR) based on 2 X 2 contingency table. An odds ratio is a relative measure of effect, which allows the comparison of the intervention group of a study.

The odds ratio is calculated using the formula (Harris *et al*, 2019)

$$\text{odds ratio} = \frac{\text{The odds of success in treatment group}}{\text{The odds of success in the control group}}$$

The odds ratio indicates how many times the event is more likely in the treatment compared to control. If the event (outcome) is positive, odds ratio will be more than 1 indicating positive impact.

Petrosino and Lavenberg (2007) conducted a study to examine the effects of “scared straight juvenile programme” on subsequent measures of crime considering 9 studies from the years 1962 to 1992. The odds ratio obtained was 1.68 which concluded the study that “scared straight intervention”, was not effective in determining the subsequent crime and likely had a backfire or toxic effect on juveniles.

Similarly, risk ratio is calculated to know the ratio of probability of success or failure for each group of study. The odds ratio provides us the ratio of odds and risk ratio provides us the ratio of probability to measure the effect size. The choice between the two is purely contextual.

The effect size can also be measured using weighted mean. As an example, let’s consider the article of Hersh *et al.* (2003) where the researcher considered 42 articles encompassing 7000 students to estimate the effects of teaching and learning with technology on students’ cognitive, affective and behavioral outcomes of learning. The researchers have considered around 28 studies on meta-analyses in educational technology where they found the effect size of 0.209 and meanwhile they have considered 42 independent articles on modern instructional technology which resulted with an effect size of 0.410. Based on the weighted

mean results, the researchers concluded that the overall effect size of modern instructional technology are nearly twice larger than the 28 meta-analytical studies conducted on traditional educational technology. This indicates that the teaching and learning with technology has a significant effect on student outcomes when compared to traditional instruction.

Modern meta-analytic methods are recent method which can be said as an extension of combined probability method. Recently, the application of meta-analysis is shifting slowly from primary studies analysis to big data. This provides weighted models which helps to obtain estimates of overall effect present in the data as well as its variance. The limitation of combined probability methods like identify heterogeneity among studies can also be estimated by applying modern meta-analytic tools.

The heterogeneity and bias can be addressed applying fixed effect model and random effect model. In fixed effect model the effect of treatment is same and the variations between results in different studies is due to random error whereas in random effect model the heterogeneity between studies are considered and the variations in study will be due to the variability in results between studies in addition to random error (Harris *et al*, 2019).

Forest Plot and Funnel Plot

A graphical representation of meta-analysis results is called Forest Plot (Figure 3) which provides results of individual studies included in the analysis along with the synthesized meta-analysis result.

Funnel plot depicted in figure 4 is also a graphical representation of meta-analysis mainly used to check the existence of publication bias in the study. The below given funnel plot from the Jos *et al* (2014) study is not suggesting that there is asymmetry in the plots and the funnel plot also predict that there is evidence for publication bias. The researcher mentions that the result of funnel plot may be due to underreporting of findings according to statistical significance or May be due to overestimating study effects.

Suppose, in the absence of publication bias, it assumes that studies with high precision will be plotted near the average, and studies with low precision will be spread evenly on both sides of the average,

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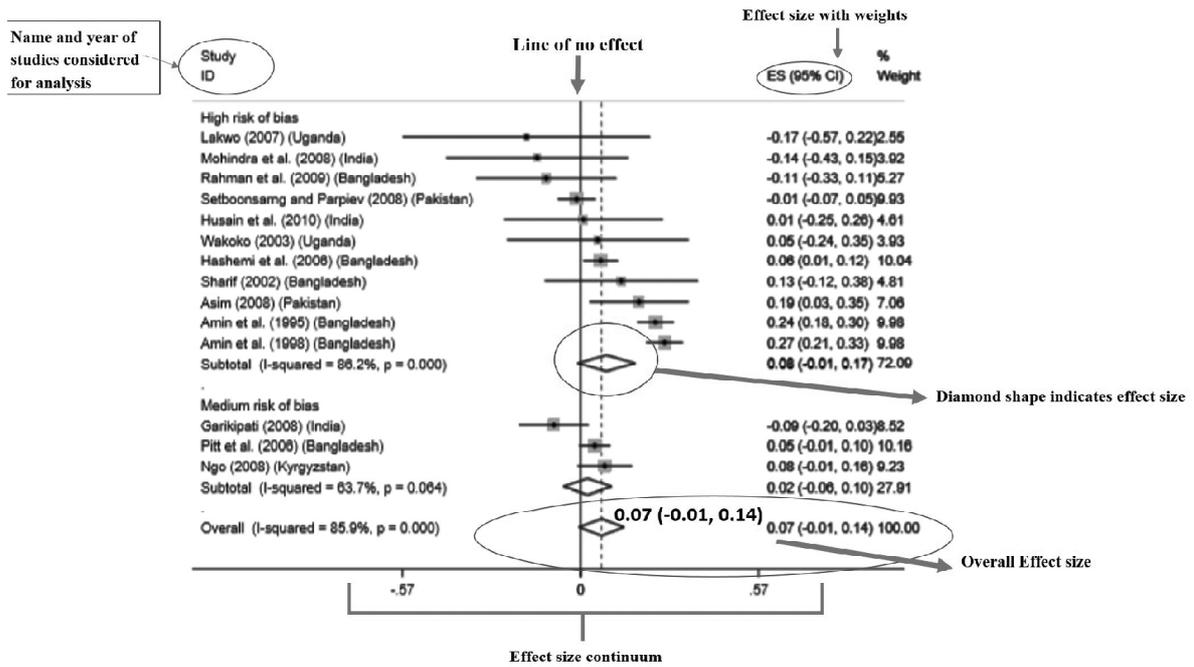


Figure 3: Forest plot considered as an example from study conducted by Jos et al. (2014)

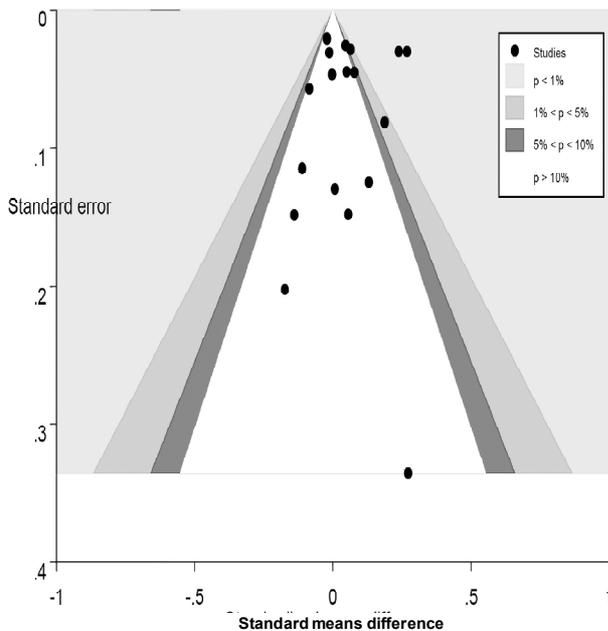


Figure 4: Funnel plot considered as an example from the study conducted by Jos et al. (2014)

Advantages of meta-analysis

Meta-analysis is an approach to synthesize the evidence in a particular area of study. Meta analysis helps to combine studies with small samples and aggregating them gives higher statistical power to the combined, it signals promising directions for future theoretical development, it provides answers to questions that were in great dispute because of conflicts in the results of various studies, evidence based, directs policy practice.

But there are certain issues in meta-analysis like search bias, publication bias and selection bias during identification and selection of studies, Heterogeneity of results and availability of information over the period which really need to be taken care.

Conclusion

Meta-analysis is a useful tool in social science research to summarize the results of several studies, which increases the statistical power of the estimate. The gap of evidence based policy research can be addressed with application of meta-analysis considering the developmental issues critically. The researcher's consciousness and critical observations will help the social science research to provide statistical full proof synthesized evidences for the policy makers to take further remedial actions.

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EFFECT OF DIFFERENT MATING SYSTEMS ON MAGNITUDE OF INBREEDING DEPRESSION IN MAIZE

P. BINDU PRIYA, T. PRADEEP, K. SUMALINI, D. VISHNU VARDHAN REDDY and K.SUPRIYA
College of Agriculture, Professor Jayashankar Telangana State Agricultural University
Rajendranagar, Hyderabad - 500 030

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ABSTRACT

This experiment was conducted for four seasons *i.e.*, *kharif* 2016, *rabi* 2016-17, *kharif* 2017 and *rabi* 2017-18 at Regional Agricultural Research Station, Palem to assess the magnitude of inbreeding depression in different types of crosses (single, three-way and double) in maize following three methods of mating systems *viz.*, self pollination, sib mating and open pollination. Six crosses (two each of single, double and three way crosses) were selected wherein three mating systems were imposed *i.e.*, selfing, sib mating and open pollination. The breeding material was evaluated for 13 traits and advanced from F₁ to F₄ generation. The results indicated that high degree of inbreeding was observed in selfing followed by sib mating and open pollination. Among all the generations, F₁ to F₂ showed high magnitude of inbreeding depression followed by F₂ to F₃ and F₃ to F₄. Irrespective of the mating system, it was observed that the magnitude of inbreeding depression was high for characters grain yield, fodder yield, ear length, number of kernels per row and 100-kernel weight while lowest inbreeding depression was observed for days to 50 per cent tasseling, days to 50 per cent silking and days to maturity. Among the two single crosses, Single Cross-1 (SC-1) recorded high inbreeding depression compared to Single Cross-2 (SC-2). Similarly Three-way Cross-2 (TWC-2) recorded more inbreeding depression than Three-way Cross-1 (TWC-1) while Double Cross-1 (DC-1) exhibited more inbreeding depression than Double Cross-2 (DC-2). Single crosses showed higher inbreeding depression over three way and double crosses. As self pollination is a severe form of inbreeding, it reduced the phenotypic values of the genotypes.

Maize is one of the most important food crops in the world and together with rice and wheat, provides at least 30 per cent of the food calories to more than 4.5 billion people in 94 developing countries (Source: www.cimmyt.org). It has dual importance as both feed and fodder besides being an important industrial product. Though 75 to 90 per cent of corn is used as animal feed, it is also consumed as human food in many parts of the world especially in Latin America, Africa, Southern Europe and some Asian countries. Industrially, maize beholds a number of roles such as manufacture of industrial alcohol, vegetable oil, corn starch, etc., while maize stalks are used in making rayon, bio-degradable plastics, biofuel and wall-boards (Omprakash *et al.*, 2017).

The development of inbreds for potential use as parental lines for producing stable and superior performing hybrids is the major goal of maize breeding programmes. As detailed by Shull (1909, 1910), self pollination, a severe form of inbreeding, reduces the complex genotypes of a breeding population to its pure-line components thereby allowing the identification of desirable genotypes by the breeder. Inbreeding increases the probability of carrying alleles that are

same by virtue of descent from a common ancestor by the progeny. Inbreeding is the process of mating between genetically related individuals and undoubtedly selfing is the strongest form of inbreeding. As a consequence of selfing, recessive genes, earlier masked in the heterozygous forms, become homozygous. These genes, if conferring to undesirable phenotypes, will result in the deterioration of the succeeding generations. In cross-pollinated crops which do not have self-incompatibility concerns, like maize, however, inbred lines for hybrid varieties are developed through selfing. Extensive studies on inbreeding depression in maize have indicated that selfing is important in inbred development because it leads to rapid gene homozygosity and desirable dominant genes can be accumulated while the undesirable ones are eliminated. However, the performance of inbred lines or lines produced from selfing decrease drastically, resulting in yield reduction, increase in the number of stunted plants, reduced plant resistance to pests and diseases and reduced growth rate (Genter, 1970; Good and Hallauer, 1977; Saleh *et al.*, 1993).

Sib-mating becomes a viable option while considering less severe inbreeding systems. Less

restrictive forms of inbreeding have been suggested for producing more vigorous inbred lines. These less restrictive forms would permit less rapid fixation of deleterious genes as compared to selfing and it is pertinent to consider the pros and cons of severe and milder forms of inbreeding for development of inbreds. Crossing among selected sibs in early generations, would be a good means to assemble adaptive genes capable of functioning in a balanced polygenic system.

The third approach is random mating of the segregating populations. The expected gains from this method would be breakup of linkage blocks that are maintained intact due to lack of recombination. The occurrence of some rare recombinants may sometimes become crucial for the success of breeding programmes. The breakup of linkage blocks and recombination of desirable genotypes may however require several generations of random mating.

In this background, a study was made to assess the magnitude of inbreeding depression in different types of crosses (single, three-way and double) in maize following three methods of mating systems viz., self pollination, sib mating and open pollination and to identify the progeny which is comparatively less depressed than others owing to the three mating systems. This information on the effects of different inbreeding systems is important since the use of less severe inbreeding systems could increase the value of these populations as line sources. The behavior of different crosses and mating systems with respect to magnitude of inbreeding depression after the third season of mating is studied.

MATERIAL AND METHODS

The research was conducted at Regional Agricultural Research Station, PJTSAU, Palem which is located in the Southern Telangana agro climatic zone of Telangana State. Geographically, it lies at 16° 35' N latitude, 78° 1' E longitude with an altitude of 662 meters above Mean Seal Level (MSL). The average rainfall of the research station is 546 mm. The soils are sandy loam type with pH of 7.2. Source of irrigation water was from bore wells and farm pond.

The experimental material used in this study comprised of six crosses including two single crosses viz., BML-14 x BML-6 (SC-1) and BML-51 x BML-32 (SC-2); two three-way crosses viz., (BML-10 x BML-

6) x BML-14 (TWC-1) and (BML-14 x BML-6) x BML-51 (TWC-2); two double crosses viz., (BML-32 x BML-6) x (BML-10 x BML-7) (DC-1) and (BML-51 x BML-7) x (BML-32 x BML-14) (DC-2). The parental lines (BML-6, BML-7, BML-10, BML-14, BML-32 and BML-51) used in the programme were developed at Maize Research Centre, Rajendranagar, Hyderabad and were crossed during *rabi* 2015-16. The resultant hybrids were raised during *kharif*, 2016 where three mating systems viz., selfing, sib-mating and random mating (out crossing) were imposed to obtain the next generation (F_2) seed. Seed obtained from three different mating systems were successively evaluated in F_2 , F_3 and F_4 generations during *rabi* 2016-17, *kharif* 2017 and *rabi* 2017-18 respectively in randomized block design with three replications each. Each replication consisted of twenty rows. Standard package of practices were adopted to raise a healthy crop. Data was recorded for the characters days to 50 per cent tasseling, days to 50 per cent silking, days to maturity, plant height (cm), ear height (cm), ear length (cm), ear circumference (cm), number of kernel rows, number of kernels row⁻¹, 100-kernel weight (g), shelling percentage (%), grain yield ha⁻¹ (kg) and fodder yield plot⁻¹ (kg) on thirty randomly selected plants. The inbreeding depression was calculated using the following formula as suggested by Griffing (1950):

$$\text{Inbreeding Depression (ID)} = \frac{F_1 - F_2}{F_2} \times 100$$

Where, F_1 – mean performance of F_1 hybrid

F_2 – mean performance of F_2

RESULTS AND DISCUSSION

The results are presented in Tables 1- 6. Perusal of the results indicated that, among the selfed progeny, SC-1 (62.55) and DC-2 (28.93) showed highest and lowest inbreeding depression respectively for the trait grain yield hectare⁻¹. Similarly, SC-2 (47.35) and DC-2 (16.58) among the sib mated progeny, TWC-2 (28.06) and SC-1 (2.34) among the open pollinated progeny exhibited maximum and minimum values of inbreeding depression for this trait. Most of the crosses like SC-1, SC-2, TWC-1, TWC-2 and DC-1 exhibited high inbreeding depression due to selfing while DC-2 progeny exhibited maximum inbreeding depression following sib-mating. For fodder yield plot⁻¹, progeny of

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SC-2 (39.52) and DC-2 (19.96) after selfing, TWC-2 (36.45) and DC-1 (25.54) after sib mating, TWC-2 (35.48) and DC-1 (-21.62) after open pollination displayed highest and lowest inbreeding depression respectively. Evaluation of the trait in all the mating systems indicated that SC-1, SC-2, TWC-2 and DC-1 exhibited maximum decline in mean values due to self pollination while it was sib-mating for the progeny of TWC-1 and DC-2.

By comparing selfed progeny of all crosses, it was observed that SC-1 (26.70) exhibited highest inbreeding depression while DC-2 (10.64) showed lowest inbreeding depression for plant height. Similarly, TWC-2 (23.31) and DC-2 (9.17) in sib mating, TWC-2 (28.74) and DC-1 (-5.24) in open mating have exhibited high and low magnitude of inbreeding depression respectively. Among the mating systems, selfing showed high inbreeding depression for plant height in SC-1, SC-2, TWC-1, DC-1 and DC-2 while sib mating showed highest inbreeding depression in TWC-2. For ear length, the progeny of SC-2 (44.03) and DC-1 (8.36) among the selfed individuals, TWC-2 (36.50) and DC-2 (21.40) among sib mated progeny, TWC-1 (17.72) and SC-2 (-2.13) among open pollinated progeny exhibited highest and lowest values of inbreeding depression respectively. Perusal of all the crosses indicated that, selfing recorded highest inbreeding depression in most of the crosses like SC-1, SC-2, TWC-1, TWC-2 and DC-2 while sib mated progeny exhibited maximum inbreeding depression in DC-1.

Within the selfed individuals, SC-1 (32.50) indicated maximum inbreeding depression while TWC-1 (15.23) indicated lowest inbreeding depression for the trait number of kernel rows ear¹. Likewise, sib mating showed maximum and minimum inbreeding depression in SC-1 (27.29) and TWC-2 (7.69) respectively while open pollinated gave highest and lowest inbreeding depression in TWC-1 (6.84) and DC-2 (-17.29) respectively. Further, it was observed that the character exhibited maximum inbreeding depression after selfing in SC-1, SC-2, TWC-2, DC-1 and DC-2 while sib mating revealed maximum inbreeding depression in TWC-1. For number of kernels per row, selfed progeny of SC-1 (60.07) and DC-1 (27.98) exhibited highest and lowest depression respectively for the trait while sib mated progeny of the crosses SC-1 (49.98) and TWC-1 (26.33) revealed maximum and lowest

inbreeding depression respectively. Among the open mated population, DC-1 (15.68) exhibited highest while TWC-1 (2.55) recorded lowest inbreeding depression. Comparison of mating systems indicated that, selfing resulted in maximum inbreeding depression in all the six crosses *i.e.*, SC-1, SC-2, TWC-1, TWC-2, DC-1 and DC-2. SC-1 (39.93) and TWC-1 (24.63) in selfed progeny, SC-1 (31.06) and DC-2 (19.78) in sib mated progeny, TWC-2 (17.04) and SC-2 (4.33) in open pollinated progeny exhibited maximum and minimum decline in values respectively for the character 100-kernel weight. Similarly, it was observed that selfing recorded highest depression for the character in SC-1, TWC-1, TWC-2, DC-1 and DC-2 while sib mating resulted in highest inbreeding depression in SC-2.

For days to maturity, among the selfed progeny of all the crosses, highest negative inbreeding depression was observed in SC-2 (30.50) while lowest was found in TWC-2 (-11.60) while among sib mated progeny highest and lowest values were observed in DC-2 (-22.84) and TWC-2 (-14.67) respectively. In the open pollinated population, highest negative inbreeding depression was found in TWC-1 (-16.46) and lowest in SC-2 (-6.41). Among the three mating systems, selfing gave highest negative inbreeding depression for the character in SC-1, SC-2, DC-1 and DC-2 while TWC-1 and TWC-2 showed in sib mating.

Irrespective of the mating system (selfing or sib mating), it was observed that the magnitude of inbreeding depression was highest for characters grain yield, fodder yield, ear length, number of kernels per row and 100-kernel weight while lowest inbreeding depression was observed for days to 50 per cent tasseling, days to 50 per cent silking and days to maturity. Similar reports of high estimates of inbreeding depression for yield related characters which are controlled by several genes were reported by Saleh *et al.*, (1993), Harris *et al.*, (1972), Halluer and Sears (1973), Cornelius and Dudley (1974). Somera *et al.*, (2018) also reported higher inbreeding depression for traits related to production like ear weight and grain weight and lower depression for flowering traits in maize. Likewise, Arnhold *et al.*, (2010) in maize and Freitas *et al.*, (2016) in cassava gave reports of high inbreeding depression in yield and yield related traits because of high contribution of heterozygous loci for these quantitative traits. Good and Halluer (1977) also observed significant differences in rates of inbreeding

depression due to selfing, half-sibbing and full-sibbing followed by selfing for plant height, cob diameter, yield and kernel weight.

Among the single, three-way and double crosses, it was observed that single crosses exhibited maximum inbreeding depression for most of the characters studied very closely followed by three-way crosses and double crosses. Inbreeding depression is a genetic phenomenon and the level to which it is expressed is a function of allele frequency, directional dominance and the number of segregating loci. Single cross hybrids are derived from only two lines indicating less chances of gene complementation. Hallauer *et al.*, (2010) stated that the narrow genetic base of single cross hybrids allows a more differentiated response compared to double cross hybrids which have a broader genetic base. Consequently, single cross hybrids bear greater losses than double cross hybrids which are less vigorous but possess greater stability because of small number of loci in heterozygosity. Similar findings were reported by Botelho *et al.*, (2016) who observed that single crosses exhibited greater inbreeding depression through inbreeding due to the greater contribution of loci in heterozygosity and consequent predominance of deviations due to dominance. In contrary, Pachecko *et al.*, (2002) reported that inbreeding depression was higher in populations with a wider genetic base and which had never been exposed to inbreeding.

Perusal of the data discernibly points that selfing resulted in maximum inbreeding depression compared to sib mating. This may be because selfing rapidly progresses towards homozygosity along with faster exposure of recessive alleles compared to sib mating. The recessive lethals, in homozygous state, reduce the vigour of the individuals carrying them thereby bringing down the population mean for various characters. Cornelius and Dudley (1974), who worked on selfed and sib mated families in maize, gave similar reports that inbreeding depression for plant height, ear height and grain yield was greater under selfing than under sib-mating. Nabila *et al.*, (2017) reported

significant differences of inbreeding depression in the selfed and half sib-mated families for the trait ear length. In agreement to our results, Porcher and Lande (2016) reported that for a given rate of inbreeding, sib-mating is more efficient at purging inbreeding depression than selfing because homozygosity of lethals increases more gradually through sib-mating than through selfing. However, Bartual and Hallauer (1976) did not observe any yield advantage for lines developed by full-sibbing over selfing, although the estimates of genetic variances for yield were two-fold greater for the full-sib lines than for selfed lines. Rodrigues *et al.*, (2001) opined that the hybrids should be developed from lines with intermediate inbreeding levels such as half-sibs though he found no significant differences in estimates of genetic parameters between selfed and full-sibbed populations. Similarly, Carlone Jr. and Russell (1988) stated that the use of lines with an intermediate inbreeding level to develop single crosses can have some advantages compared to the use of highly inbred lines in terms of vigor and stability. Open pollinated population showed cryptic behavior coupled with display of negative values of inbreeding depression for some characters. This may be due to no control on the genotype epistasis of the pollinating agent in this type of mating system. According to Botello *et al.*, (2016) negative values for inbreeding depression may indicate a large number of loci in homozygosity, which results in genetic stability leading to less depreciation of the character.

The results indicated that high degree of inbreeding was observed in selfing followed by sib mating and open pollination. Among the generations F_1 to F_2 showed high magnitude of inbreeding followed by F_2 to F_3 and F_3 to F_4 . Between two single crosses SC-1 recorded high inbreeding depression than SC-2, similarly TWC-2 recorded more than TWC-1 and DC-1 more than DC-2. Since, self pollination is a severe form of inbreeding, reduces the phenotypic values of the genotypes. Similar results were reported by Pradeep and Sumalini (2003) in cotton.

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Table 1: Inbreeding depression after three mating systems in SC-1 cross in Maize

S.No.	Character	Selfing				Sib mating				Open pollination			
		After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄
1.	DT	-7.36	-4.52	-4.98	-17.79	-4.58	-3.46	-6.17	-14.89	2.83	-4.52	-6.17	-7.83
2.	DS	-5.34	-4.56	-2.72	-13.13	-1.97	-2.46	-4.91	-9.60	5.44	-1.21	-9.16 **	-4.47
3.	DM	-9.79 **	-4.41	-5.53	-20.97	-8.91 **	-4.69	-2.50	-16.86	-1.84	3.77	-13.02 **	-10.76
4.	PH	19.88 **	5.79	2.89	26.70	15.14 **	0.71	4.27	19.34	5.52	7.96	-4.58	9.06
5.	EH	9.60 **	11.20 **	4.42	23.27	10.78 **	10.45 **	8.24 *	26.69	6.35	-8.14	2.23	0.98
6.	EL	20.54 **	13.98 **	10.07 **	38.54	22.81 **	3.87	5.60	29.96	9.63 **	8.94 *	-18.36 **	2.61
7.	EC	17.82 **	5.95	11.87 **	31.88	8.53 **	6.95	5.65	19.70	9.25 **	-19.47 **	15.97 **	8.89
8.	KR	8.27 *	12.05 **	13.05 **	29.85	13.53 **	11.30 **	5.20	27.29	-7.02	12.88 **	-13.71 **	-6.02
9.	KPR	31.00 **	32.33 **	14.47 **	60.07	15.08 **	26.32 **	20.05 **	49.98	21.63 **	-18.05 **	-6.18	1.77
10.	SW	22.49 **	8.41 *	15.38 **	39.93	14.30 **	15.60 **	4.70	31.06	18.56 **	-3.54	-6.74	10.00
11.	SP	9.46 **	2.28	2.73	13.94	4.34	9.62 **	0.32	13.82	0.90	0.43	-2.76	-1.41
12.	GY (kg ha ⁻¹)	39.53 **	20.97 **	21.63 **	62.55	19.12 **	19.13 **	11.35 **	42.01	11.73 **	8.89 **	-21.44 **	2.34
13.	FY (kg plot ⁻¹)	20.27 **	16.82 **	16.50 **	44.62	21.05 **	17.60 **	9.88 **	41.37	3.05	-4.87	-5.52	-7.28

DT - Days to 50 per cent tasselling, DS - Days to 50 per cent silking, DM - Days to maturity, PH - Plant Height (cm), EH - Ear height (cm), EL - Ear length (cm), EC - Ear circumference (cm), KR - Number of kernel rows, KPR - Number of kernels row⁻¹, SW - 100-kernel weight (g), SP - Shelling percentage (%), GY - Grain yield hactare⁻¹ (kg), FY - Fodder yield plot⁻¹ (kg)

Table 2: Inbreeding depression after three mating systems in SC-2 cross in Maize

S.No.	Character	Selfing				Sib mating				Open pollination			
		After I season	After II season	After III season	Total ID (%)	After I season	After II season	After III season	Total ID (%)	After I season	After II season	After III season	Total ID (%)
		F ₁ to F ₂	F ₂ to F ₃	F ₃ to F ₄	F ₁ to F ₄	F ₁ to F ₂	F ₂ to F ₃	F ₃ to F ₄	F ₁ to F ₄	F ₁ to F ₂	F ₂ to F ₃	F ₃ to F ₄	F ₁ to F ₄
1.	DT	-17.44 **	-2.89	-5.13	-27.02	-13.39 **	-2.80	-3.13	-20.21	-7.06	0.21	6.47	0.08
2.	DS	-21.06 **	-2.11	-5.26	-30.11	-14.47 **	-6.15	-1.36	-23.17	-11.82 **	3.01	2.92	-5.28
3.	DM	-20.16 **	-7.96	-0.60	-30.50	-11.25 **	-3.37	-3.33	-18.83	-8.39 *	1.30	0.54	-6.41
4.	PH	15.20 **	8.89 **	2.72	24.84	10.09 **	2.46	0.97	13.15	-6.50	15.14 **	-0.05	9.58
5.	EH	28.25 **	8.67 **	2.37	36.02	15.81 **	0.18	4.13	19.44	-0.20	14.19 **	-5.17	9.58
6.	EL	18.86 **	10.41 *	23.00 **	44.03	12.45 **	21.99 **	2.02	33.08	22.58 **	-12.64 **	-17.13 **	-2.13
7.	EC	9.10 *	7.78	4.37	19.83	16.77 **	0.34	1.15	18.01	-5.59	12.55 **	-8.56 **	-0.24
8.	KR	16.67 **	6.00	13.83 **	32.50	4.44	4.07	6.64	14.42	-20.00 **	1.39	13.15 **	-2.78
9.	KPR	23.32 **	29.50 **	19.28 **	56.37	20.52 **	18.01 **	10.60 **	41.74	10.45 **	-4.40	2.14	8.51
10.	SW	16.09 **	5.09	11.73 **	29.70	15.12 **	15.65 **	4.42	31.56	14.58 **	-5.44	-6.22	4.33
11.	SP	10.34 **	3.80	2.99	16.32	2.71	4.03	1.67	8.19	3.10	8.22 *	-10.64 **	1.60
12.	GY (kg ha ⁻¹)	32.89 **	17.28 **	12.83 **	51.60	23.42 **	19.78 **	14.29 **	47.35	8.90 **	9.66	-17.65 **	3.18
13.	FY (kg plot ⁻¹)	16.19 **	15.75 **	14.34 **	39.52	16.76 **	12.93 **	4.45	30.75	12.51 **	-10.43 **	-0.26	3.14

DT - Days to 50 per cent tasseling, DS - Days to 50 per cent silking, DM - Days to maturity, PH - Plant height (cm), EH - Ear height (cm), EL - Ear length (cm), EC - Ear circumference (cm), KR - Number of kernel rows, KPR - Number of kernels row⁻¹, SW - 100-kernel weight (g), SP - Shelling percentage (%), GY - Grain yield hectare⁻¹ (kg), FY - Fodder yield plot⁻¹ (kg)

Table 3: Inbreeding depression after three mating systems in TWC-1 cross in Maize

S.No.	Character	Selfing				Sib mating				Open pollination			
		After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄
1.	DT	-6.49	-3.77	-2.14	-12.86	-4.74	-6.08	0.49	-10.57	7.84	7.37	-12.72 **	3.77
2.	DS	-6.02	-4.20	-1.34	-11.96	-4.96	-4.76	-0.89	-10.92	-6.59	18.43 **	-8.96	5.27
3.	DM	-8.24 *	-5.70	-1.91	-16.59	-8.73 **	-7.09	-2.00	-18.76	4.69	-9.30 **	-2.64	-6.93
4.	PH	6.63	4.63	1.87	12.62	6.07	3.85	2.09	11.57	8.66 **	7.79	-12.88 **	4.93
5.	EH	7.58	12.44 **	3.88	22.22	11.96 **	6.71	4.27	21.37	9.18 **	-11.02 **	19.53 **	18.87
6.	EL	27.38 **	8.80 **	1.12	34.51	19.02 **	3.99	8.00 *	28.47	-3.63	10.89 **	10.89 **	17.72
7.	EC	14.44 **	10.87 **	0.45	24.09	12.95 **	1.35	7.53	20.58	2.02	0.55	-5.78	-3.08
8.	KR	10.38 **	3.94	1.54	15.23	12.58 **	9.09 **	7.25	26.29	13.91 **	-6.15	-1.93	6.84
9.	KPR	25.51 **	9.32 **	3.26	34.65	10.32 **	11.64 **	7.03	26.33	19.50 **	-3.64	-16.80 **	2.55
10.	SW	17.37 **	7.27	1.63	24.63	5.68	10.06 **	5.65	19.96	10.94 **	0.89	-7.30	5.29
11.	SP	7.76	1.40	0.60	9.60	8.59 **	1.02	1.84	11.19	12.52 **	-16.38 **	6.61	4.92
12.	GY (kg ha ⁻¹)	21.23 **	12.69 **	22.24 **	46.52	22.49 **	20.36 **	12.13 **	45.75	14.14 **	-2.95	11.21 **	21.52
13.	FY (kg plot ⁻¹)	6.17	6.65	12.55 **	23.40	12.18 **	11.35 **	13.32 **	32.52	33.54 **	-12.86 **	-5.89	20.58

DT - Days to 50 per cent tasseling, DS - Days to 50 per cent silking, DM - Days to maturity, PH - Plant height (cm), EH - Ear height (cm), EL - Ear length (cm), EC - Ear circumference (cm), KR - Number of kernel rows, KPR - Number of kernels row⁻¹, SW - 100-kernel weight (g), SP - Shelling percentage (%), GY - Grain yield ha⁻¹ (kg), FY - Fodder yield plot⁻¹ (kg)

Table 4: Inbreeding depression after three mating systems in TWC-2 cross in Maize

S.No	Character	Selfing				Sib mating				Open pollination			
		After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄
1.	DT	-3.88	-4.53	-1.92	-10.67	-9.91**	-4.29	-6.80	-22.42	-11.06**	5.61	1.28	-3.49
2.	DS	-3.51	-3.85	-3.90	-11.68	-10.50**	-5.21	-7.16	-24.57	-16.67**	9.81**	2.81	-2.27
3.	DM	-3.65	-6.72	-0.89	-11.60	-5.45	-7.01	-1.62	-14.67	-9.49**	3.54	6.98	1.76
4.	PH	13.27**	9.06**	1.83	22.57	9.71**	11.05**	4.51	23.31	-0.51	32.47**	-4.99	28.74
5.	EH	17.36**	9.39**	3.71	27.90	13.17**	16.79**	3.72	30.44	5.36	6.52	5.82	16.68
6.	EL	26.36**	11.78**	4.25	37.80	15.33**	18.69**	7.76	36.50	20.54**	9.26**	-21.20**	12.60
7.	EC	27.02**	6.39	9.81**	38.39	1.52	9.12**	12.75**	21.91	22.01**	2.87	-5.30	20.23
8.	KR	13.29**	9.68**	1.79	23.08	0.23	6.78	0.75	7.69	10.49**	6.25	-18.33**	0.70
9.	KPR	27.23**	18.00**	20.47**	52.54	14.64**	9.23**	19.68**	37.76	8.62**	10.01**	-17.62**	3.27
10.	SW	21.36**	17.42**	2.02	36.37	18.46**	9.53**	5.79	30.50	8.43*	21.92**	-16.03**	17.04
11.	SP	13.63**	0.95	0.55	14.92	5.36	1.12	4.38	10.52	10.04**	0.39	-6.49	4.58
12.	GY (kg ha ⁻¹)	39.31**	31.65**	6.97	61.41	15.06**	11.70**	9.86**	32.40	18.58**	20.64**	-11.33**	28.06
13.	FY (kg plot ⁻¹)	23.81**	14.81**	2.91	36.99	20.92**	12.12**	8.56**	36.45	34.19**	13.04**	-12.73**	35.48

DT - Days to 50 per cent tasseling, DS - Days to 50 per cent silking, DM - Days to maturity, PH - Plant height (cm), EH - Ear height (cm), EL - Ear length (cm), EC - Ear circumference (cm), KR - Number of kernel rows, KPR - Number of kernels row⁻¹, SW - 100-kernel weight (g), SP - Shelling percentage (%), GY - Grain yield ha⁻¹ (kg), FY - Fodder yield plot⁻¹ (kg)

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Table 5: Inbreeding depression after three mating systems in DC-1 cross in Maize

S.No.	Character	Selfing				Sib mating				Open pollination			
		After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄
1.	DT	-5.42	-3.16	-1.26	-10.11	-7.51	-1.86	-0.52	-10.08	7.20	8.74	-15.98 **	1.79
2.	DS	-6.38	-0.57	-2.37	-9.52	-8.92 **	-1.17	-0.84	-11.11	7.46	4.40	-12.18 **	0.76
3.	DM	-17.78 **	-3.14	-2.59	-24.64	-18.77 **	-4.40	-2.17	-26.68	-5.41	-1.67	-5.69	-13.27
4.	PH	13.27 **	0.09	0.31	13.62	7.72	2.02	2.64	11.98	-4.33	8.32	-10.02 **	-5.24
5.	EH	15.17 **	10.31 **	1.88	25.35	10.88 **	8.35 *	5.13	22.51	0.08	10.98 **	-1.46	9.75
6.	EL	1.46	4.76	2.36	8.36	6.26	20.07 **	3.25	27.51	6.62	-9.91 **	14.72 **	12.47
7.	EC	19.38 **	7.11	0.12	25.20	8.13 *	2.67	5.02	15.08	-0.98	-9.56 **	17.39 **	8.60
8.	KR	2.99	10.43 **	6.35	18.62	11.26 **	5.18	1.64	17.24	1.15	9.30 **	-15.38 **	-3.45
9.	KPR	20.16 **	3.38	6.63	27.98	9.94 **	9.75 **	9.55 **	26.48	2.60	5.79	8.10 *	15.68
10.	SW	18.03 **	11.17 **	2.18	28.78	11.11 **	7.65	5.31	22.27	0.57	6.89	6.57	13.50
11.	SP	8.31 *	0.77	1.71	10.57	2.71	0.45	2.55	5.62	3.34	-5.41	6.14	4.36
12.	GY (kg ha ⁻¹)	16.72 **	19.53 **	8.66 **	38.79	8.78 **	8.00 *	6.45	21.49	1.79	7.29	-5.83	3.64
13.	FY (kg plot ⁻¹)	15.26 **	10.49 **	7.04	29.49	8.12 *	6.94	12.91 **	25.54	29.26 **	-29.83 **	-32.43 **	-21.62

DT - Days to 50 per cent tasseling, DS - Days to 50 per cent silking, DM - Days to maturity, PH - Plant height (cm), EH - Ear height (cm), EL - Ear length (cm), EC - Ear circumference (cm), KR - Number of kernel rows, KPR - Number of kernels row⁻¹, SW - 100-kernel weight (g), SP - Shelling percentage (%), GY - Grain yield ha⁻¹ (kg), FY - Fodder yield plot⁻¹ (kg)

Table 6: Inbreeding depression after three mating systems in DC-2 cross in Maize

S.No.	Character	Selfing				Sib mating				Open pollination			
		After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄	After I season F ₁ to F ₂	After II season F ₂ to F ₃	After III season F ₃ to F ₄	Total ID (%) F ₁ to F ₄
1.	DT	-10.66**	-1.59	-0.13	-12.56	-6.70	-1.97	-0.16	-8.98	-2.82	4.02	-2.23	-0.89
2.	DS	-11.55**	-1.24	-0.81	-13.84	-7.50	-0.51	-0.69	-8.79	-4.10	3.91	-3.45	-3.48
3.	DM	-20.78**	-3.49	-0.66	-25.82	-4.79	-2.14	-8.83**	-16.49	-11.62**	3.85	-7.81	-15.70
4.	PH	2.29	4.50	4.25	10.64	-4.32	10.78**	2.41	9.17	-0.57	9.81**	-11.04**	-0.72
5.	EH	10.03**	7.38	1.58	17.99	5.46	6.30	4.40	15.31	-6.16	-0.78	6.32	-0.23
6.	EL	18.64**	7.96	12.15**	34.22	9.54**	4.30	9.20**	21.40	10.31**	13.54**	-7.26	16.83
7.	EC	9.19**	3.93	1.40	13.98	2.67	4.26	14.62**	20.43	-2.99	-2.74	13.16**	8.12
8.	KR	23.81**	1.31	9.30**	31.80	16.29**	4.19	8.13*	26.32	-2.01	-4.67	-9.86**	-17.29
9.	KPR	16.21**	12.79**	4.38	30.13	17.47**	14.46**	5.45	33.25	8.05*	19.49**	-21.79**	9.84
10.	SW	17.74**	7.82	11.48**	32.88	8.73**	6.88	5.61	19.78	6.19	12.02**	-15.69**	4.52
11.	SP	1.84	6.43	3.06	10.96	3.59	0.09	3.58	7.12	5.13	-2.81	-1.03	1.46
12.	GY (kg ha ⁻¹)	13.36**	10.90**	7.93	28.93	7.72	6.54	3.28	16.58	-17.85**	21.23**	5.80	12.55
13.	FY (kg plot ⁻¹)	6.99	9.98**	4.41	19.96	15.48**	9.13**	11.59**	32.10	-16.90**	14.00**	-18.19**	-18.82

DT - Days to 50 per cent tasseling, DS - Days to 50 per cent silking, DM - Days to maturity, PH - Plant height (cm), EH - Ear height (cm), EL - Ear length (cm), EC - Ear circumference (cm), KR - Number of kernel rows, KPR - Number of kernels row⁻¹, SW - 100-kernel weight (g), SP - Shelling percentage (%), GY - Grain yield hactare⁻¹ (kg), FY - Fodder yield plot⁻¹ (kg)

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CORRELATION AND PATH ANALYSIS STUDIES FOR YIELD RELATED AND NUTRITIONAL TRAITS IN RECOMBINANT INBRED LINES OF RICE MTU1010 X BR2655

RAMYA RATHOD¹, L.V. SUBBA RAO², C.N. NEERAJA², K.B. ESWARI¹ and D. SRINIVASA CHARY¹

¹Department of Genetics and Plant Breeding, College of Agriculture
Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad - 500 030

²ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad - 500 030

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ABSTRACT

The present study was undertaken to estimate the correlation and path analysis for yield, yield attributing and nutritional traits in 190 F₈ RILs derived from MTU1010 X BR2655 along with two parents during Rabi-2016-17. Grain yield per plant had significant positive association with panicle length, number of productive tillers per plant, number of filled grains per panicle and 1000-grain weight. Path analysis revealed that 1000-grain weight exerted the highest positive direct effect on grain yield followed by plant height, number of filled grains per panicle, days to 50 per cent flowering and number of productive tillers per plant indicating that selection for these characters was likely to bring about an overall improvement in grain yield per plant directly.

Rice (*Oryza sativa* L.) is a major staple food for more than half of world's populace and provides two thirds of calorie intake for more than three billion people in Asia while one-third of calorie intake for nearly 1.5 billion people in Africa and Latin America. Poor grain micronutrient content (iron, zinc and pro-vitamin A) in cereals is the primary cause of nutritional deficiency related disorders prevalent among populations having cereals based diet, especially those dwelling in developing world (Cakmak, 2000). Biofortification is a genetic approach which aims at biological and genetic enrichment of food stuffs with vital nutrients (vitamins, minerals and proteins). It is one of the best methods to alleviate malnutrition and development of new cultivars with elevated concentrations of micronutrients using conventional breeding and biotechnological approaches (Graham *et al.*, 1999; Zimmermann and Hurrell, 2002). Grain yield being a complex polygenic character, direct selection based on these traits would not yield fruitful results without giving due importance to their genetic background. Hence understanding the relationship between yield, quality and its components is of paramount importance for making the best use of these relationships in selection. Character association derived by correlation coefficient, forms the basis for selecting the desirable plant, aiding in evaluation of relative influence of various component characters on grain yield. Path coefficient analysis discerns correlation into direct and indirect effects. In the present study, an attempt was made to understand the association and

path analysis of quality and component characters for grain yield in rice genotypes.

MATERIAL AND METHODS

The experimental material for the present study consisted of a 190 recombinant inbred lines (RILs) mapping population derived from a cross of MTU1010 x BR2655. The RILs were planted along with parents in randomized block design with 3 replications each at a spacing of 20 x 15 cm. All the recommended package of practices were adopted besides providing necessary prophylactic plant protection measures to raise a good crop. Five plants were randomly selected and observations were recorded for yield and yield attributing traits. Days to 50 per cent flowering was recorded on plot basis. The traits studied were: Days to 50 per cent flowering, Plant height (cm), Number of productive tillers, Panicle length (cm), Number of filled grains per panicle, Grain yield per plant (g) and 1000-grain weight (g).

Grain iron and zinc concentration in the unpolished rice grains were determined by X – Ray fluorescence Spectrometry (XRF) (EDXRF, model - X-supreme 8000). Grain iron and zinc concentration were determined by X – Ray fluorescence Spectrometry (XRF) (EDXRF, model- X-supreme 8000). In XRF the preselected wavelength of incident X – rays expel the electrons from the inner most orbit followed by the transfer of one of the electrons from the outermost orbit to the inner most orbit leading to release of specific

wavelength of X – rays. The energy of the emitted radiation is specific for a particular atom. Therefore, it is simultaneously identified and quantified by the detector. Samples are presented for analysis in cuvettes on a sample carousel, enabling multiple samples to be analysed in a single run (Paltridge *et al.*, 2012). Qualitative analysis measures the energies of the radiation emitted by the sample to determine the elements present in the sample. Quantitative analysis measures the intensity of the emitted energies to determine the concentration of each element present in the sample. This instrument is quite useful in non – destructive determination of relative iron and zinc concentrations in rice samples with more ease. The correlation and path analysis was carried out using Indostat software.

RESULTS AND DISCUSSION

Correlation

The efficiency of selection for yield mainly depends on the direction and magnitude of association between yield and its component characters and also among themselves. Character association provides information on the nature and extent of association between pairs of metric traits and helps in selection for the improvement of the character. Genotypic correlation coefficients between yield, yield attributing and nutritional characters are presented in Table.1. Grain yield per plant had significant positive association with panicle length, number of productive tillers per plant, number of filled grain per panicle and 1000-grain weight indicating these traits are indirectly involved in the improvement of grain yield. Non-significant positive association was recorded with days to 50 per cent flowering. Plant height, grain zinc and iron concentration had significant negative association with grain yield. This indicates while improving grain yield due care is to be given to component traits *viz.*, panicle length, number of productive tillers per plant, number of filled grains per panicle and 1000-grain weight as these traits are positively associated with grain yield and indirect selection for these traits might improve the grain yield.

Days to 50 per cent flowering recorded a non-significant positive association with grain yield per plant, 1000-grain weight and number of filled grains per panicle, it showed negative and significant association with plant height and non-significant negative for panicle length, number of productive tillers per plant,

grain zinc and iron concentration. Similar findings were recorded by Sarker *et al.* (2014) for number of filled grains per panicle, Rao *et al.* (2014) for 1000-grain weight and panicle length, Nandan *et al.* (2010), Rao *et al.* (2014) for grain yield per plant and Ajmera *et al.* (2017) for grain zinc and iron concentration.

Plant height had shown a significant negative association with grain yield per plant, grain zinc and iron concentration, positive non-significant association with panicle length, number of productive tillers per plant and 1000-grain weight, negative non-significant association with number of filled grains per panicle. Similar with Rao *et al.* (2014) for number of productive tillers per plant, Sala *et al.*, (2015) for panicle length, Dhurai *et al.* (2014) for 1000-grain weight, Nagesh *et al.* (2012) for grain zinc and iron concentration, Reddy *et al.* (2013), Patel *et al.* (2014), Biswash *et al.* (2015), Thippeswamy *et al.* (2016) and Priya *et al.* (2017) with grain yield per plant. This results suggests that plant height could be considered as criterion for selection of higher yield as they were inter related among themselves showing significant positive correlation.

Panicle length registered significant positive association with grain yield. Revealed that selection for panicle length could improve the grain yield of rice. A non-significant positive association was found with number of filled grains per panicle and non-significant negative association with number of productive tillers per plant, 1000-grain weight, grain zinc and iron concentration. Similar were reported by Rao *et al.* (2014) for days to 50 % flowering, Sala *et al.* (2015) for plant height, Rahman *et al.* (2014) for number of filled grains per panicle, Nagesh *et al.* (2012) for grain zinc concentration, Dhurai *et al.* (2014) for 1000- grain weight and number of productive tillers per plant, Thippeswamy *et al.* (2016) and Priya *et al.* (2017) for grain yield per plant.

Number of productive tillers per plant exhibited negative non-significant correlation with number of filled grains per panicle, 1000-grain weight, grain zinc and iron concentration. Grain yield per plant had a significant positive association with this trait suggesting that direct selection for higher number of productive tillers per plant may increase the grain yield per plant. Similar with Rao *et al.* (2014) for plant height and 1000-seed weight, Dhurai *et al.* (2014) for panicle length and Nagesh *et al.* (2012) for grain zinc concentration, Ratna *et al.*

(2015); Ashok *et al.* (2016); Priya *et al.* (2017) for grain yield per plant.

Number of filled grains per panicle exhibited a non-significant positive correlation with 1000-grain weight whereas non-significant negative correlation with grain zinc and iron concentration. This character has shown significant positive association with grain yield per plant. Similar with Nandan *et al.* (2010), Sarker *et al.* (2014) for days to 50 % flowering, Nandan *et al.* (2010) for plant height, Rahman *et al.* (2014) for panicle length, Biswash *et al.* (2015), Thippeswamy *et al.* (2016), Lakshmi *et al.* (2017) for 1000 seed weight, Lakshmi *et al.* (2017) and Priya *et al.* (2017) for grain yield per plant. Nagesh *et al.* (2013) for grain zinc and iron concentration.

1000-grain weight showed highly significant positive correlation with grain yield per plant and non-significant negative correlation with grain zinc and iron concentration. This trait acts as a selection criterion for improvement of grain yield per plant. Reported same with Ashok *et al.* (2016), Lakshmi *et al.* (2017), Priya *et al.* (2017) for grain yield per plant and Nagesh *et al.* (2013) for grain zinc and iron concentrations.

Grain zinc and iron concentration showed a negative significant correlation with grain yield per plant, this indicates that this trait does not acts as a selection criterion for improvement of grain yield per plant. The results were in accordance with Nagesh *et al.* (2013) for grain yield per plant.

Path analysis

The genotypic and phenotypic correlations were estimated to determine direct and indirect effects of yield and yield contributing characters. If the correlation coefficient between a casual factor and the effect is almost equal to its direct effect, it explains the true relationship and a direct selection through this trait may be useful. If the correlation coefficient is positive, but the direct effect is negative or negligible, the indirect effects appear to be the cause of that positive correlation. In such situation the other factors are to be considered simultaneously for selection. However if the correlation coefficient is negative but direct effect is positive and high, a restriction has to be imposed to nullify the undesirable indirect effects in order to make

use of direct effect. Path coefficient analysis shown in Table. 2 revealed that 1000-grain weight exerted the highest positive direct effect on grain yield followed by plant height, number of filled grains per panicle, days to 50 per cent flowering and number of productive tillers per plant indicating that the selection for these characters was likely to bring about an overall improvement in grain yield per plant directly. Therefore, it is suggested that preference should be given to these characters in the selection programme to isolate superior lines with genetic potentiality for high yield in rice genotypes. Negative direct effect on grain yield was exhibited by panicle length, grain zinc and iron concentration.

High direct effect of 1000-grain weight on grain plant yield was reported by Thippeswamy *et al.* (2016), Tejaswini *et al.* (2016), Kalyan *et al.* (2017), Lakshmi *et al.* (2017), Priya *et al.* (2017). Plant height, number of filled grains per panicle, number of productive tiller per plant and days to 50 per cent flowering also had direct positive effect and positive genotypic correlation with grain yield. Rahman *et al.* (2014), Ashok *et al.* (2016), Lakshmi *et al.* (2017) and Priya *et al.* (2017) reported positive direct effect of plant height, number of productive tillers and number of filled grains per panicle. Nikhil *et al.* (2014), Ratna *et al.* (2015), Tejaswini *et al.* (2016) and Priya *et al.* (2017) reported positive direct effect of days to 50 per cent flowering.

Negative direct effect of panicle length, grain zinc and iron concentration on grain yield was observed. The direct effect and correlation coefficient of grain zinc and iron concentration were negative, so the direct selection for these traits to improve the yield will not be desirable. Thippeswamy *et al.* (2016), Lakshmi *et al.* (2017) and Priya *et al.* (2017) also reported negative direct effect of panicle length on grain yield. Nagesh *et al.* (2013) reported negative direct effect of grain zinc and iron concentration on grain yield.

CONCLUSION

Present study isolated four characters *viz.*, Days to 50 per cent flowering, Number of productive tillers per plant, Number of filled grains per panicle and 1000-grain weight out of eight characters studied which are ideal to consider in a selection strategy for selection of genotypes with high grain yield.

Table 1. Phenotypic and Genotypic correlation coefficient analysis for yield contributing and nutritional characters in rice

Character	Days to 50% flowering	Plant height (cm)	Panicle length (cm)	No of productive tillers per plant	No of filled grains per panicle	1000 grain weight (g)	Grain zinc concentration (ppm)	Grain Iron concentration (ppm)	Grain yield per plant (g)
Days to 50% flowering	G	-0.2627 **	-0.0145	-0.0874	0.0709	0.2333	-0.1530	-0.0963	0.0907
	P	-0.2453 **	-0.0140	-0.0869	0.0702	0.2330	-0.1524	-0.0957	0.0902
Plant Height (cm)	G	1.0000	0.1345	0.0912	-0.0247	0.0233	-0.1888 *	-0.1286 *	-0.1028 *
	P		0.1337	0.0905	-0.0243	0.0228	-0.1884 *	-0.1281 *	-0.1023
Panicle Length (cm)	G		1.0000	-0.0050	0.0153	-0.0389	-0.1101	-0.1567	0.2064 **
	P			-0.0047	0.0150	-0.0384	-0.1100	-0.01559	0.2061 **
Number of productive tillers plant ⁻¹	G			1.0000	-0.0551	-0.0406	-0.0753	-0.1253	0.2379 **
	P				-0.0546	-0.0401	-0.0751	-0.1250	0.2374 **
Number of filled grains per panicle	G				1.0000	0.0203	-0.0803	-0.1072	0.2151 *
	P					0.0201	-0.0800	-0.1069	0.2149 **
1000 Grain Weight (g)	G					1.0000	-0.0414	-0.0851	0.3947 **
	P						-0.0411	-0.0847	0.3944 **
Grain zinc concentration (ppm)	G						1.0000	-0.2137	-0.4343 *
	P							-0.2133	-0.4341 **
Grain iron concentration (ppm)	G							1.0000	-0.3562 **
	P								-0.3558 **

P -represents phenotypic correlation coefficient; G- represents genotypic correlation coefficient, *Significant at 5 percent level, **Significant at 1 percent level

Table 2. Direct and indirect effects of yield attributing and nutritional traits in rice

Character	Days to 50% flowering	Plant height (cm)	No of productive tillers plant ⁻¹	Panicle length (cm)	No of filled grains per panicle	1000 grain weight (g)	Grain zinc (ppm)	Grain iron (ppm)	Grain yield per plant (g)
Days to 50% flowering	0.0174	-0.0039	-0.0101	-0.0020	0.0101	0.0028	-0.0024	-0.0028	0.0870
Plant height (cm)	-0.0372	0.1278	0.0114	0.0151	-0.0028	0.0033	-0.0145	-0.0167	0.2510 **
No of productive tillers plant ⁻¹	-0.0110	0.0041	0.0171	-0.002	-0.0007	-0.0009	-0.0016	-0.0009	0.0389
Panicle length (cm)	0.0021	-0.0009	0.0012	-0.0039	-0.0006	0.0009	0.0007	0.1034	0.0360
No. of filled grains per panicle	0.0034	-0.0014	-0.0030	0.0009	0.0503	0.0010	-0.0043	-0.0035	0.1028 *
1000-grain weight	0.0521	0.0082	-0.0153	-0.0141	0.0077	0.3680	-0.0151	-0.0240	0.3935 **
Grain zinc concentration (ppm)	0.0379	0.0625	0.0120	0.0339	0.0237	0.0123	-0.2976	-0.3187	-0.4248 **
Grain iron concentration (ppm)	0.0412	0.0543	0.0151	0.0091	0.0326	0.0156	-0.3247	-0.2541	-0.3247

Residual effect = 0.8050, **Bold values**- direct effects, **Normal values**-indirect effects; *Significant at 5 percent level, **Significant at 1 percent level

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BIOEFFICACY OF COMMONLY USED INSECTICIDES AGAINST RICE BROWN PLANTHOPPER, *Nilaparvata lugens* (STÅL)

V. RATNAKAR¹, V. JHANSI LAKSHMI², C. SRINIVAS¹, R. JAGADEESHWAR¹ and SATENDRA K MANGRAUTHIA²

¹Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad - 500 030

²ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad - 500030

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ABSTRACT

Studies on the bio-efficacy of commonly used insecticides against brown planthopper (BPH), *Nilaparvata lugens* (Stål) population were carried out at ICAR-Indian Institute of Rice Research, Hyderabad during 2017. To assess efficacy of insecticides against BPH population, the insecticides were diluted to specified doses with water and sprayed on 60 day old potted TN1 rice plants with the help of fine atomizer and 7-9 day old nymphs of BPH were released and confined to treated plants. Observations on BPH mortality were recorded at 2, 24, 48 and 72 hours after release of nymphs. The results revealed that after two hours of treatment, dichlorvos recorded highest per cent mortality *i.e.* 62.5. Dinotefuran and chlorpyrifos recorded 100 per cent mortality after 24 hours of insecticidal treatment followed by dichlorvos (88.7%), thiamethoxam (85.0%), fipronil (85.0%), ethiprole (79.2%), monocrotophos (70.0%), acephate (65.0%), imidacloprid (53.7%), combination product ethiprole + imidacloprid (48.7%) and pymetrozine (38.7%). Buprofezin recorded least per cent mortality *i.e.* 32.5. With the progression of time (48 and 72 hours after application of insecticides), the mortality of BPH nymphs increased in all the treatments. Dinotefuran, dichlorvos, chlorpyrifos, thiamethoxam, monocrotophos, ethiprole and fipronil were found to be highly effective against BPH while acephate, ethiprole + imidacloprid, imidacloprid and pymetrozine were moderately effective. Buprofezin failed to control BPH.

Rice brown planthopper (BPH), *Nilaparvata lugens* (Stal) (Hemiptera: Delphacidae) is the most important sucking insect pest attacking rice crop throughout the rice growing countries. Extensive yield losses due to BPH have been reported from several parts of the country (Chandana *et al.* 2015). The emergence of BPH as a key pest was due to the suitable microclimate created by the cultivation of high yielding varieties and hybrids (Krishnaiah and Jhansi Lakshmi, 2012). Both the nymphs and adults remain at the base of the rice plant and suck the sap from the phloem and xylem resulting in yellowing, wilting, drying up and death of the rice plant. Under field conditions, the damage spreads in a circular fashion and is termed as "hopper-burn". If timely control measures are not taken up, the entire field could be affected within a span of 15-20 days. In addition to direct feeding, BPH also transmits viral diseases like grassy stunt and ragged stunt (Ling, 1977). Use of insecticides is the most sought after strategy for BPH management by farmers despite several draw backs such as development of insecticide resistance and resurgence (Baehaki *et al.* 2016). BPH has become a very serious problem causing severe yield losses due to

monoculturing of rice in an extensive area, use of susceptible rice varieties, availability of irrigation water in addition to indiscriminate use of insecticides. Among the different groups of insecticides used against BPH, monocrotophos, acephate (organo-phosphates) imidacloprid, thiamethoxam, dinotefuran (neonicotinoids), buprofezin (insect growth regulator), pymetrozine (feeding inhibitor), and fipronil (phenyl pyrazole compounds) are important ones. There is a need to assess the bioefficacy of insecticides against brown planthopper and to monitor the development of insecticides resistance in the field populations. As a part of this study, bioefficacy of insecticides was assessed against the glasshouse BPH population unexposed to insecticides.

MATERIAL AND METHODS

Insecticides

Fresh and ready to use insecticide formulations were obtained from the manufacturing companies (Table 1). The test insecticides include three neonicotinoids *viz.*, imidacloprid 17.8 SL (Confidor), thiamethoxam 25 WG (Actara) and dinotefuran 20 SG (Token); four organophosphates *viz.*, monocrotophos

36 SL (Monostar), acephate 75 WP (Starthene), dichlorvos 76 EC (Nuvan) and chlorpyrifos 20 EC (Dursban); two phenyl pyrazoles viz., fipronil 5 SC (Regent) and ethiprole 100 SC (Ethiprole). In addition, pymetrozine (Chess), a pyridine azomethine compound, insect growth regulator cum chitin synthesis inhibitor, Buprofezin 25 SC (Applaud) and one combination product containing Ethiprole 40% + Imidacloprid 40% (Glamore) were also evaluated.

Toxicity tests for bioefficacy of insecticides

The tests were carried out under controlled glass house conditions at a temperature of $30 \pm 5^\circ\text{C}$ and RH of $60 \pm 5\%$, following the methodology standardized by Jhansi Lakshmi *et al.* 2010a. To assess the efficacy of insecticides, all the insecticides were tested at doses as detailed in Table 1. The insecticides were diluted to the required concentrations with tap water and sprayed on 60 day old potted rice plants with the help of fine atomizer upto runoff stage. Tap water spray without any insecticide served as control. The spray deposits were allowed to dry in the shade. Twenty 7-9 day old BPH nymphs collected from glass house BPH population were confined to the treated plants with mylar cages covered with muslin cloth. Observations on BPH mortality were recorded at 2, 24, 48 and 72 hours after release of nymphs. The insects that were unable to move when touched with camel hair brush were considered as dead insects. Per cent mortalities were computed, angular transformed and statistically analyzed in completely randomized block design (CRBD).

RESULTS AND DISCUSSION

Results pertaining to the efficacy of insecticides on the third instar nymphs of BPH are presented in the Table 2. Dichlorvos registered highest BPH nymphal mortality (62.5%) after two hours of application followed by fipronil (53.7%), dinotefuran (42.5%), chlorpyrifos (38.7%), combination product, ethiprole 40% + imidacloprid 40% 80 WG (36.2%) and thiamethoxam (35.0%) while imidacloprid, buprofezin, pymetrozine and acephate recorded very low mortality of 21.2, 11.2, 10.0 and 7.5 per cent, respectively.

After 24 hours of application, dinotefuran and chlorpyrifos were the most effective in reducing BPH nymphal population (100.0% mortality) followed by dichlorvos (88.7 % mortality), thiamethoxam (85.0%),

fipronil (85.0%), ethiprole (79.2%), monocrotophos (70.0%) and acephate (65.0 % mortality). Imidacloprid, ethiprole + imidacloprid 80 WG, pymetrozine and buprofezin recorded 53.7, 48.7, 38.7 and 32.5 per cent mortality, respectively.

After 48 hours of application apart from dinotefuran and chlorpyrifos, dichlorvos also recorded cent per cent mortality of BPH nymphs, followed by ethiprole, fipronil and monocrotophos which recorded 95.0, 95.0 and 92.5 per cent mortality, respectively. Thiamethoxam, imidacloprid, combination product ethiprole + imidacloprid 80 WG and acephate showed 90.0, 78.7, 76.2 and 75.0 per cent mortality, respectively. Buprofezin and pymetrozine recorded 45.0 and 43.7 per cent mortality, respectively. With the progression of time after application of insecticides, the mortality of BPH nymphs increased in all the treatments. Seventy two hours after treatment, dinotefuran, monocrotophos, chlorpyrifos, dichlorvos, imidacloprid, thiamethoxam, ethiprole, fipronil and ethiprole + imidacloprid 80 WG (Glamore) recorded cent per cent mortality, followed by acephate (92.5%) and pymetrozine (75.0%). Buprofezin recorded only 60.0% mortality.

Dinotefuran exhibited 85.0% mortality after one day of exposure, and similar results were observed by Jhansi Lakshmi *et al.* (2010a). Dinotefuran was quite effective against BPH under field conditions (Ghosh *et al.* 2014). It showed good degree of effectiveness in the present study (93-100% mortality) also. Monocrotophos and acephate were found effective against BPH population with 92.5 -100% nymphal mortality which is in conformity with Randeep *et al.* (2016). In the present study, results related to chlorpyrifos are in conformity with the findings of Kharbade *et al.* (2015) who reported that chlorpyrifos application was highly effective against BPH. The combination product ethiprole + imidacloprid exhibited 100% mortality at 72 hours after release of nymphs and similar results were observed by Jhansi Lakshmi *et al.* (2010b). Pymetrozine caused 38.7% mortality at 24 hours showing slow action initially and the result is in concurrence with that of Atanu and Naik, (2017) and Jhansi Lakshmi *et al.* (2010b). The previous results indicated that buprofezin could kill all the exposed BPH population within three days (Shashank *et al.* 2012). However, in the present study, it could exhibit only 60.0 per cent mortality even after 3 days of exposure.

Table 1: Details of insecticides used in the present investigation

S.No	Common Name	Trade name and formulation	Insecticide Group	Source of supply
1.	Acephate	Starthene 75SP	Organophosphates	Swal Corporation Limited
2.	Buprofezin	Applaud 25SC	Chitin synthesis inhibitors	Rallis India Limited
3.	Chlorpyrifos	Dursban 20 EC	Organophosphates	Dow Agro Science
4.	Dichlorvos	Nuvan 76 EC	Organophosphates	Insecticides (India) Limited
5.	Dinotefuran	Token 20SG	Neonicotinoids	Indofil Industries Limited
6.	Fipronil	Regent 5SC	Phenyl pyrazoles	Bayer Crop Science Limited
7.	Ethiprole	Ethiprole 100SC	Phenyl pyrazoles	Bayer Crop Science Limited
8.	Imidacloprid	Confidor 17.8 SL	Neonicotinoids	Bayer Crop Science Limited
9.	Monocrotophos	Monostar 36SL	Organophosphates	Swal Corporation Limited
10.	Pymetrozine	Chess 50WG	Pyridine azomethine	Syngenta India Limited
11.	Thiamethoxam	Actara 25WG	Neonicotinoids	Syngenta India Limited
12.	Ethiprole + imidacloprid	Glamore 80WG	Combination insecticide	Bayer Crop Science Limited

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Table 2: Toxicity of insecticides to glasshouse brown planthopper population at different exposure periods

S. No.	Insecticides	Dose g or ml /l water	Mortality of BPH nymphs (%)			
			2 h	24 h	48 h	72 h
1.	Acephate (Starthene) 75 SP	1.0 g	7.5 (16.4)f	65.0 (53.7)e	75.0 (60.6)e	92.5 (76.2)b
2.	Monocrotophos (Monostar) 36 SL	2.0 ml	11.2 (19.5)f	70.0 (56.8)de	92.5 (78.7)abc	100.0 (90.0)a
3.	Chlorpyrifos (Dursban) 20 EC	2.5 ml	38.7 (38.5)cd	100.0 (90.0)a	100.0 (90.0)a	100.0 (90.0)a
4.	Dichlorvos (Nuvan) 76 EC	1.0 ml	62.5 (52.2)a	88.7 (70.5)b	100.0 (90.0)a	100.0 (90.0)a
5.	Imidacloprid (Confidor) 17.8 SL	0.5 ml	21.2 (27.4)e	53.7 (47.16)f	78.7 (66.8) cde	100.0 (90.0)a
6.	Thiamethoxam (Actara) 25 WG	0.5 g	35.0 (36.2)d	85.0 (67.4)b	90.0 (74.2)bcd	100.0 (90.0)a
7.	Dinotefuran (Token) 20 SG	0.4 g	42.5 (40.6)c	100.0 (90.0)a	100.0 (90.0)a	100.0 (90.0)a
8.	Ethiprole 40% + imidacloprid 40% (Glamore) 80 WG	0.25 g	36.2 (37.0)d	48.7 (44.3)f	76.2 (61.4)de	100.0 (90.0)a
9.	Ethiprole 100 SC	0.25 ml	40.0 (39.2)cd	79.2 (63.0)c	95.0 (80.8)ab	100.0 (90.0)a
10.	Fipronil (Regent) 5 SC	2.0 ml	53.7 (47.1)b	85.0 (67.4)b	95.0 (80.8)ab	100.0 (90.0)a
11.	Pymetrozine (Chess) 50 WG	0.6 g	10.0 (18.4)f	38.7 (38.5)g	43.7 (41.4)f	75.0 (60.6)c
12.	Buprofezin (Applaud) 25 SC	2.0 ml	11.2 (19.5)f	32.5 (34.6)h	45.0 (42.1)f	60.0 (51.0)d
13.	Untreated Control (Water spray)		0.0 (0.0)g	0.0 (0.0)i	0.0 (0.0)g	0.0 (0.0)e
	S.Em ±		1.1	1.4	4.5	3.0
	C.D (0.05)		3.1	4.0	12.9	8.6
	C.V		6.2	4.5	9.6	7.1

*Figures in parentheses are angular transformed values

*Values in a column followed by same letter were on par at $P = 0.05$ by LSD

Based on the study, it can be deduced that dinotefuran, monocrotophos, dichlorvos thiamethoxam, chlorpyrifos, ethiprole and fipronil exhibited good bioefficacy while acephate, ethiprole + imidacloprid 80 WG, imidacloprid and pymetrozine were

moderately effective. Buprofezin was least effective against BPH.

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EFFECT OF N AND K FERTIGATION LEVELS ON YIELD ATTRIBUTES, YIELD AND WATER PRODUCTIVITY OF COLOURED CAPSICUM (*Capsicum annuum* var. *grossum*) HYBRIDS UNDER SHADE NET

K. SHILPA, M. UMA DEVI, K. AVIL KUMAR and S. SRIDEVI
Water Technology Centre, Professor Jayashankar Telangana State Agricultural University
Rajendranagar, Hyderabad - 500 030

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Water and fertilizers are the most important inputs in agriculture and the efficient use of these resources is important for maximizing yield. Fertigation enables the application of water soluble fertilizers more uniformly and efficiently in the crop root zone. It also helps in the application of nutrients according to the crop requirement at different growth stages.

Bell pepper is an important vegetable crop grown worldwide occupying an area of 25 thousand hectares, producing 313 thousand metric tonnes (MOA & FW, 2018). The fruit of capsicum is seeded berry, smooth, thick fleshed, blocky, 3-4 lobed, square to rectangular in shape, colour usually green when immature, turning red/yellow at maturity. Protected cultivation is an emerging technology which mitigates the adverse effects of harsh climate and enables the production of quality produce in the present scenario of unpredictable climate. By considering the various structures with respect to cost, shade nets are low cost emerging technology when compared to green house and polyhouse which can be exploited by the resource poor farmers. Shade nets are perforated plastic materials used to cut down the solar radiation and prevent scorching or wilting of leaves caused by marked temperature increase with in leaf tissue from strong sunlight.

The present experiment on N and K fertigation levels for different coloured capsicum hybrids was conducted during *rabi* 2018-2019 at Horticulture farm, Water Technology Centre, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad. The soil of the experimental site was sandy loam in texture with a pH of 7.8, electrical conductivity of 0.32 dS m⁻¹, low in organic carbon

(0.27 %), low in available nitrogen (142 kg ha⁻¹), medium in available phosphorus (55.2 kg P ha⁻¹) and low in available potassium (162.8 kg K ha⁻¹). The irrigation water used in the experiment was neutral (pH=6.96) and categorized under the Class II (C₂S₁).

The experiment was carried out inside a green coloured, tape type 50 % shade net. It was laid out in a split plot design consisting of four main treatments (N and K fertigation levels) (F₅₀ - 50 % recommended dose of N and K, F₇₅ - 75 % recommended dose of N and K, F₁₀₀ - 100 % recommended dose of N and K and F₁₂₅ - 125 % recommended dose of N and K), three sub treatments (V₁- Green hybrid (Indra), V₂- Yellow hybrid (Orabelle) and V₃- Red hybrid (Bomby) and replicated thrice. The 100 % recommended dose of fertilizer (RDF) 2-1 100, 80 and 60 kg N, P₂O₅ and K₂O ha⁻¹, respectively was applied in the form of urea, single super phosphate (SSP), and white murate of potash (MOP). A common dose of phosphorous was applied uniformly to all the treatments at basal. The total fertigations given are 37 at three days interval. Details of fertigation schedule are presented in Table 1.

Coloured capsicum seeds were sown in protrays on 1st August 2018 and one month old seedlings were transplanted on 1st September 2018 in a zig zag manner in a paired row pattern on raised beds. Irrigation was scheduled at 0.8 E pan based on pan evaporation data of USWB class A pan evaporimeter. The total water applied through drip at 0.8 E pan (common to all the treatments) was 555.5 mm, water applied for nursery including special operations was 16 mm. The effective rainfall during the crop growth period was 31.4 mm as a result total water applied

was 602.9 mm. In total green fruits were harvested in six pickings, red and yellow fruits were harvested in five pickings.

Mean fruit length varied from 8.20 cm to 10.37 cm and 8.72 cm to 9.66 cm among the fertigation levels and capsicum hybrids respectively. Among the fertigation levels, F_{125} (10.37 cm) recorded the highest fruit length which was found to be on par with F_{100} (9.97 cm) and was significantly superior over other levels. F_{50} (8.20 cm) recorded the lowest fruit length and was found to be on par with F_{75} (8.83 cm). Among the hybrids, red hybrid (V_3) (9.66 cm) recorded the highest fruit length. It was observed that yellow coloured capsicum (V_2) recorded 9.7 % and 9.6 % decrease in Mean fruit length (cm) over red hybrid (V_3) and green hybrid (V_1) respectively. Higher levels of potassium maintained a favourable osmotic balance and thus resulted in cell expansion and increase in fruit length. These results were in harmony with Rajendra Kumar *et al.* (2017) and Gill (2018) under shade net condition.

Mean fruit width varied from 6.41 cm to 7.64 cm and 6.87 cm to 7.22 among the fertigation levels and capsicum hybrids respectively. Among the fertigation levels, F_{125} (7.64 cm) recorded the highest fruit width which was found to be on par with F_{100} (7.51 cm) and was significantly superior over other levels. It was noticed that the fertigation with F_{125} , F_{100} and F_{75} resulted in 19.2 %, 17.2 % and 5.1 % increase in mean fruit width (cm) when compared to F_{50} .

The highest total number of fruits plant⁻¹ among the main treatments was recorded with F_{125} (14.1) and was found to be on par with F_{100} (13.0) and was superior over other treatments. F_{50} which recorded 25.53 %, 19.23 % and 7.89 % decrease in total fruit number over F_{125} , F_{100} and F_{75} respectively. Among the hybrids the highest number of fruits plant⁻¹ was recorded with green hybrid (V_1) (15.1) followed by yellow hybrid (V_2) (11.8). It was noticed that there was increase in fruit number with increase in the N and K fertigation levels. These findings were also in conformity with Rajendra Kumar *et al.* (2017), Gill (2018) with coloured capsicum hybrids in shade net condition. Similar results were reported by Hegazi *et al.* (2017), Sanchita *et al.* (2014), Bhuvaneshwari *et al.* (2013) and Malik *et al.* (2011) where fruit yield increased with increase in the dose of fertilizers. It might be due to better micro climate and

increased translocation of photosynthates towards the economic parts thus resulting in formation of more flowers and there by more number of fruits. Green hybrid Indra recorded significantly the highest fruits followed by yellow and red hybrids.

Average fruit weight varied significantly with the fertigation levels. It was observed that all the fertigation levels F_{75} , F_{100} and F_{125} recorded significantly higher average fruit weight over F_{50} (68.3 g) which recorded the lowest average fruit weight. A 26.35 %, 18.59 %, 14.20 % of increase in average fruit weight was observed in F_{125} , F_{100} and F_{75} over F_{50} . Red hybrid (V_3) recorded the highest average fruit weight (87.7 g) followed by yellow hybrid (V_2) (78.7 g) and the lowest was observed with green coloured capsicum (V_1) (68.8 g). These results are in accordance with Kurubetta and Patil (2009) who found that the hybrid Bomby recorded higher fruit weight under naturally ventilated polyhouse.

The highest fruit yield (Table 3) was recorded with F_{125} (41693 kg ha⁻¹) and was significantly higher over other treatments. Total fruit yield increased gradually with increase in the N and K fertigation level up to 125 %. Among the hybrids there was a significant difference observed for the total fruit yield. The highest total fruit yield was recorded with green hybrid (V_1) (38.5 t ha⁻¹). These results were in harmony with Dubey *et al.* (2017) in capsicum under shade net and Sanchita *et al.* (2014) who found that lowest fruit yield was with lowest fertiliser dose in capsicum.

Among the main treatments, the highest water productivity was observed with F_{125} (6.92 kg m⁻³). Among the capsicum hybrids, green hybrid (V_1) (6.39 kg m⁻³) recorded highest water productivity. This might be due to the increase in yield with increase in the fertigation level that contributed to increase in the water productivity. Increase in WUE was due to increase in total fruit yield with 125 % N, P and K application was reported by Ramachandrappa *et al.* (2010).

Based on the results obtained, it can be concluded that during *rabi* season under 50 % shade net condition, application of 125 % RD of N and K through fertigation on every fourth day from 10 DAT to 153 DAT was found to be beneficial for growing of capsicum and regarding capsicum hybrids, green hybrid gave higher yields.

EFFECT OF N AND K FERTIGATION LEVELS ON YIELD

Table 1. Details of N and K fertigation schedule of coloured capsicum hybrids under shade net

S.No	Crop growth stage	DAT	Number of fertigations	N %	K ₂ O %
1.	Transplanting to plant establishment	1 to 13 DAT	2	10.00	10.00
2.	Vegetative stage	14 to 45 DAT	8	30.00	20.00
3.	Flower initiation to Fruit set	46 to 77 DAT	7	20.00	20.00
4.	Harvesting stage	78 to 153 DAT	20	40.00	50.00
		Total	37	100.00	100.00

Table 2. Mean fruit length (cm), fruit width (cm), Total number of fruits plant⁻¹ and Average fruit weight (g) of coloured capsicum hybrids as influenced by different N and K fertigation levels under shade net during *rabi* 2018-19

Treatments	Mean fruit length (cm)	Mean fruit width (cm)	Total number of fruits plant ⁻¹	Average fruit weight (g)
Main – Fertigation				
F ₅₀ - 50 % RDF of N and K	8.20	6.41	10.5	68.3
F ₇₅ - 75 % RDF of N and K	8.83	6.74	11.4	78.0
F ₁₀₀ - 100 % RDF of N and K	9.97	7.51	13.0	81.0
F ₁₂₅ - 125 % RDF of N and K	10.37	7.64	14.1	86.3
S.E±	0.20	0.20	0.31	1.91
C.D (P=0.05)	0.71	0.72	1.11	6.75
Sub – Hybrids				
V ₁ - Green hybrid (Indra)	9.65	7.22	15.1	68.8
V ₂ – Yellow hybrid (Orabelle)	8.72	7.15	11.8	78.7
V ₃ – Red hybrid (Bomby)	9.66	6.87	9.1	87.7
S.E±	0.16	0.11	0.32	1.60
C.D (P=0.05)	0.48	NS	0.96	4.82
Interaction	NS	NS	NS	NS
Hybrids at same fertigation level				
S.E±	0.35	0.35	0.54	3.31
C.D (P=0.05)	NS	NS	NS	NS
Fertigation at same or different hybrids				
S.E±	0.33	0.27	0.61	3.23
C.D (P=0.05)	NS	NS	NS	NS

Note: Mean fruit length (cm), fruit width (cm) and average fruit weight (g) is a mean of first, third and fifth picking

Table 3. Total fruit yield (kg ha⁻¹) and water productivity (kg m⁻³) of coloured capsicum hybrids as influenced by different N and K fertigation levels under shade net during rabi 2018-19

Treatments	Total fruit yield (kg ha ⁻¹)	Water productivity (kg m ⁻³)
Main - Fertigation		
F ₅₀ - 50 % RDF of N and K	26052	4.32
F ₇₅ - 75 % RDF of N and K	31665	5.26
F ₁₀₀ - 100 % RDF of N and K	35538	5.90
F ₁₂₅ - 125 % RDF of N and K	41693	6.92
S.E±	1836	-
C.D (P=0.05)	6476	-
Sub - Hybrids		
V ₁ - Green hybrid (Indra)	38481	6.39
V ₂ - Yellow hybrid (Orabelle)	32369	5.37
V ₃ - Red hybrid (Bomby)	30362	5.04
S.E±	1372	-
C.D (P=0.05)	4147	-
Interaction		
Hybrids at same fertigation level		
S.E±	3180	-
C.D (P=0.05)	NS	-
Fertigation at same or different hybrids		
S.E±	2896	-
C.D (P=0.05)	NS	-

Note: Total fruit yield is a sum of six pickings of green and five pickings each of red and yellow hybrids respectively.

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EVALUATION OF SUPERIOR LINES OF F₄ GENERATION DERIVED FROM THE CROSS IMPROVED SAMBA MAHSURI X YPK267 FOR YIELD AND YIELD RELATED TRAITS

P. JAYAMMA¹, CH. ANURADHA¹, P. SENGUTTUVEL², T. RAMESH¹ and R.M. SUNDARAM^{2*}

¹IBT, Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad - 500030

²ICAR-Indian Institute of Rice Research (IIRR), Rajendranagar, Hyderabad - 500030

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Rapid population growth and global demand for rice consumption has been estimated to rise from 700 million tons (mt) to 852 mt in 2035. In India, where population is steadily growing, there is a need to increase rice production from 103 mt to at least 136 mt by the year 2050 (<http://www.icar-iirr.org/IIRR%20Vision%202050.pdf>). Therefore, improvement in the yield potential of rice has to be the major strategy to meet the global rice demand. It is becoming increasingly difficult to break yield ceiling by using conventional breeding (Peng *et al.*, 1999). Grain yield in rice is a complex trait determined by its three component traits: number of panicles, number of grains per panicle, and grain weight; which are typical quantitative traits. The present study was aimed to enhance yield potential of Improved Samba Mahsuri (ISM) using marker assisted selection for presence of yield target traits i.e. high grain number, strong culm and panicle branching which are governed by the genes *Gn1a*, *SCM2* and *OsSPL14* respectively. Phenotypic evaluation of F₄ population derived from the cross ISM × YPK-267 was carried out for growth and yield related traits. Promising lines were identified for further use in rice breeding programs.

The F₄ population was developed by crossing improved Samba Mahsuri (ISM) and YPK-267. ISM is a high yielding, fine grain, popular rice variety. Bacterial blight (BB) resistance was developed by introgression of three BLB resistance genes *Xa21*, *xa13* and *xa5* using Marker Assisted Back cross breeding approach by Sundaram *et al.* (2008). The present study was conducted using molecular breeding approach to enhance the yield potential and productivity of the elite

parent, ISM. The high yield target genes used in the present study were *Gn1a* (gene associated with high Grain number, Ashikari *et al.* (2005), *SCM2* (gene associated with strong Culm, Ookawa *et al.*, 2010 and Terao *et al.*, 2010) and *SPL-14* (high panicle branching, gene associated with increasing grain number and dense panicle; Miura *et al.*, 2010 and Jiao *et al.*, 2010).

A total of 175 F₁ superior plants were subjected for marker analysis with the *Xa21* specific marker, pTA248 of which 140 heterozygous plants were confirmed as true F₁s. These 140 plants were analyzed with gene specific markers for target yield genes, a total of 71 plants were found to be heterozygous for three target yield enhancing genes viz., *Gn1a*, *SCM2* and *OsSPL14* only these plants were forwarded to produce F₂. A total of 240 F₂ plants were screened with the gene specific overlapping markers for *Gn1a*, *SCM2* and *OsSPL14* only 12 plants were observed to be homozygous for the target yield genes forwarded to F₃ generation. A set of selected F₄ 832 plants evaluated for the presence of target genes using gene specific markers and BLB resistance genes. When these 832 F₄ plants were subjected for analysis with markers specific for the three bacterial blight resistance genes, viz., *Xa21* (pTA248) specific for *Xa21* (Ronald *et al.*, 1992), *xa13* (Hajira *et al.*, 2016) and *xa5* (Hajira *et al.*, 2016), only 55 plants found to be homozygous for target three genes and had desirable yield dense panicle and strong culm characteristics, those 55 plants evaluated under field for target yield traits (grain number, culm thickness for strong culm and high value for panicle branching) and other key yield traits like plant height,

Table 1. Analysis Of Variance (ANOVA) and Variability on yield and its attributing characters of F₄ breeding lines.

Source	df	Day to 50% Flowering	Plant Height	Tiller Number	Culm Thickness	Panicle branching	Panicle Length	Number of Chaffy grains	Single Plant Yield	Grain Number per plant	1000 Grain weight
Replications	1	72.009	128.75	0.036	0.573	1.08	33.274	31.64	12.244	107.21	18.08
treatments	54	78.4521 ***	54.0077 ***	8.8814 ***	0.55960.87 **	23.94 **	15.800 ***	589.82 **	578.79 **	1408.53 **	15.66 **
Error	54	0.675	0.64	0.878	0.05	0.11	0.11	0.06	44.65	50.97	2.31
CD		1.1547	3.3096	1.407	0.3187	1.083	4.769	1.0575	7.989	10.028	0.23
CV		6.29	6.39	3	14.345	14.75	10.96	9.461	25.57	15.78	0.688
GCV%		6.8507	5.9879	20.648	11.667	14.244	5.643	7.1056	25.135	11.96	12.84
PCV%		6.91	6.7717	21.589	12.79	14.6	14.2749	7.291	26.5822	11.71	11.175
h ² %		98.3	78.12	91.54	83.2	95.1	15.6	94.95	89.42	86.0	94.32
GA		16.322	10.412	8.326	1.213	8.794	1.525	8.402	41.255	5.164	5.114

CV- Coefficient of variance; CD - Critical difference at 5%; PCV- Phenotypic coefficient of variation; GCV- Genotypic coefficient of variation; p value-probability level; ± -Standard error and data given are mean of two replications of *Kharrif-2018*.

***Significance at p d" 0.01 level of probability

productive tiller number, panicle length, thousand grain weight, grain number and single plant yield.

From this study, a total of fiftyfive lines were identified with desirable traits and agronomically similar to recurrent parent and were used to evaluate for key agro morphological traits. Of these, few lines had early flowering. In case of panicle primary and secondary branching separation, few lines were found to have heavy or thick panicles with more number of grains per panicle (~380 to 405 grains per panicle) than recurrent parent, ISM (~260 to 275 grains per panicle). Although, fifteen genotypes were found to have high single plant yield and more grains (4000 grain number, with 55% increase in number of grains per plant, while the recurrent parent ISM has, 2436 grain number). From this present study, a promising line YP-ISM 40 had thick culm diameter (5 mm) than that of the ISM (3.2 mm). This line also had more number of filled grains per panicle (~280, yield ~59.3 grams/plant) than that of the recurrent parent (~220, yield ~31.5 grams per plant).

Many investigators have studied the rice grain yield and yield-related traits, such as plant height, panicle weight, spikelets per m², growth duration, days to flowering and grain weight (Reddy *et al.*, 1997). In this study, superior plants were selected to identify ISM breeding lines carrying target genes *Gn1a* (Grain number), *SCM2* (culm thickness for Strong culm), *OsSPL14* (more Panicle branching), From this study, in phenotypic evaluation a promising line YP-40 was high yielding and with more grains per panicle, and high value for panicle branching and more single/ total plant yield. High heritability with more genetic advance as percentage of mean were observed for single plant yield (89.4 per cent and 41.255), high heritability with moderate genetic advance as percentage of mean were observed for plant height days to fifty per cent flowering (98.3 per cent and 16.322), plant height (78.2 per cent and 10.414). High heritability with low genetic advance was observed for tiller number (91.5 per cent and 8.326), thousand grain weight (94.3% and 5.114), total number of grains per plant (86% and 5.164) and culm thickness (83.2% and 1.213). High heritability along with low genetic advance is attributable to non-additive gene action.

The present study was focused on introgression of yield target traits to improve the yield potential of the recurrent parent ISM. Phenotypic selection of these promising lines for the target gene would be more effective for yield improvement in rice and these promising lines would be valuable materials for breeders engaged in the development of high yielding cultivars.

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GENETIC VARIABILITY STUDIES IN BC₂F₂ POPULATION DERIVED FROM SAMBA MAHSURI*2/*O. rufipogon* OF RICE

M. SRIDHAR¹, M. SUJATHA¹, R.M. SUNDARAM², DIVYA BALAKRISHNAN²,
D. SRINIVASA CHARY¹, C. GIREESH^{2*}

¹Department of Genetics and Plant Breeding, College of Agriculture
Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad - 500 030

²ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad - 500 030

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Rice crop is endowed with a rich genetic variability. However, intensive modern breeding efforts further narrowed the rice gene pool because of selection pressure in favour of favourable alleles and hence the modern rice cultivars have narrow genetic base for most of the agronomically important traits including yield.

In order to broaden the rice genetic base, crosses were made between elite cultivars and genetically distant relatives such as landraces and varieties from different gene pools. *Oryza rufipogon* is a progenitor of cultivated rice (*Oryza sativa*) and known to possess beneficial yield enhancing QTLs. Hence, an attempt was made to introgress the yield QTLs from *O. rufipogon* to Samba Mahsuri by molecular marker-assisted approach and back cross population was developed. A BC₂F₂ population obtained from a cross between Samba mahsuri and *O. rufipogon* which was developed to introgress the yield QTL's from *O. rufipogon* to *O. sativa* was evaluated for genetic variability, heritability and genetic advance for yield and yield contributing traits in BC₂F₂ population obtained from a cross between Samba mahsuri and *O. rufipogon* (IRGC 106106).

The field experiment was conducted during *khari*, 2018 at ICAR-Indian Institute of Rice Research Farm, ICRISAT campus, Patancheru, Hyderabad, India. The experimental site situated at an altitude of 542.3 meters above mean sea level, 17°19' North latitude and 78°23' East longitude. A BC₂F₂ population comprising of 190 ILs developed from the cross between *O. sativa* (Samba Mahsuri) X *O. rufipogon* (IRGC 106106) along with two checks (Samba Mahsuri and RNR 15048) were used for the study. All the entries under study were sown separately in raised

bed nursery. Twenty one days old seedlings of each genotype were transplanted in 5 rows of 3 m length by adopting a spacing of 20 cm between rows and 15 cm between plants within a Augmented Randomized Complete Block Design. The two checks were replicated five times. All the necessary precautions were taken to maintain uniform plant population and recommended package of practices were adopted besides providing necessary prophylactic plant protection measures to raise a good crop.

Observations were recorded on a total of ten metric characters. Among them seven characters *viz.*, plant height, panicle length, total number of tillers per plant, number of productive tillers per plant, number of filled grains per panicle, number of chaffy grains per panicle, spikelet fertility and single plant yield were recorded on five randomly selected plants in each plot. Days to 50 % flowering and thousand grain weight were recorded on plot basis. These characters were measured as per the standard techniques.

The data collected on all the characters were subjected to standard methods of analysis of variance (Federer, 1956). Phenotypic and genotypic coefficient of variations (Burton, 1952), heritability (broad sense) (Lush, 1940) and genetic advance as a percent of mean (Johnson *et al.*,) 1955 were estimated.

The analysis of variance revealed the existence of significant differences among the genotypes for all the traits (Table 1), indicating the presence of considerable genetic variability among the experimental material under study. The range of mean values, genotypic and phenotypic coefficient of

variation, heritability and genetic advance as per cent of mean (Table 2) for 192 genotypes (190 introgressed lines and two checks) were calculated for yield and its contributing traits.

Phenotypic coefficients of variation values were slightly higher than the genotypic coefficient of variation values for all the characters indicating less influence of environment. Therefore, response to direct selection may be effective in improving these traits.

Among all the traits under study five traits viz., chaffy grains per panicle (71.18/72.30), single plant yield (55.58/56.19), productive tillers per plant (39.93/41.55), filled grains per panicle (37.31/38.00) and total number of tillers per plant (22.97/42.72) exhibited high estimates of genotypic and phenotypic coefficients variations. These results are in conformity with the findings of Abebe *et al.* (2017) for chaffy grains per panicle, Sarma *et al.* (2018) and Asem *et al.* (2019) for single plant yield and total number of tillers per plant and Umarani *et al.* (2017), Singh and Verma (2018) for productive tillers per plant and Thippeswamy *et al.* (2016) and Lakshmi *et al.* (2017) for filled grains per panicle.

Genotypic and phenotypic coefficients of variation were moderate for plant height (14.55/14.68) and spikelet fertility (11.45/11.56). Gokulakrishnan *et al.*, (2014), Harsh *et al.*, (2015) and Rohit *et al.*, (2017) also observed similar results for plant height and Padmaja *et al.*, (2008) for spikelet fertility. The estimates of genotypic and phenotypic coefficients of variation were found to be low for days to 50 % flowering (5.42/6.42). These findings are in accordance with those of Singh and Verma (2018) and Umarani *et al.* (2019). 1000-grain weight had (17.10/21.99) moderate and high genotypic and phenotypic coefficient of variations, respectively. However, panicle length (9.13/11.04) has expressed low and moderate values of GCV and PCV, respectively. Similar results were reported by Tripathi *et al.*, (2017) for 1000-grain weight and Bhati *et al.* (2015) for panicle length.

All the characters under investigation except total number of tillers per plant (28.90 %) expressed high estimates of heritability in broad sense ranging from 60.46 to 98.29%. Among all the characters, highest heritability was recorded for plant height (98.29%) followed by spikelet fertility (98.05%). High heritability for quantitative characters indicated that these

characters are less influenced by environment and there could be great correspondence between phenotypic and breeding value and the scope for genetic improvement of these characters through selection. Out of ten traits under study, days to 50% flowering (9.46%) and panicle length (15.57%) expressed low and moderate genetic advance as per cent of mean, respectively. Remaining all the traits exhibited high estimates of genetic advance as per cent of mean, among them number of chaffy grains per panicle (93.23%) acquired highest value, followed by single plant yield (91.42 %).

Among the all characters studied, low heritability coupled with high genetic advance was observed for total number of tillers per plant suggesting that the character is governed by additive gene effects but low heritability could be due to high environmental effects. High heritability accompanied with low genetic advance for days to 50% flowering is indicative of non-additive gene action and could be due to favourable influence of environment rather than genotype. The selection for this trait may not be effective. This result was in agreement with the findings of Mohan *et al.*, (2016) and Singh and Verma (2018).

Panicle length exhibited high heritability coupled with moderate genetic advance. Singh and Verma (2018) also obtained similar results for panicle length. High heritability coupled with moderate genetic advance as per cent of mean, suggested that the expression of this trait was mostly influenced by additive type of gene action. Hence its response to selection would be effective in improving the seed yield.

All the remaining characters viz., plant height, number of productive tillers per plant, number of filled grains per panicle, number of chaffy grains per panicle, spikelet fertility, 1000-grain weight and single plant yield expressed high heritability coupled with high genetic advance, which indicated the preponderance of additive gene action in controlling of the traits. Hence direct selection of such characters would be effective. These results were in accordance with the findings of Singh and Verma (2018) and Asem *et al.*, (2019) for plant height, Umarani *et al.*, (2017) and Sarma *et al.*, (2018) for number of productive tillers per plant and single plant yield, Thippeswamy *et al.*, (2016) and Lakshmi *et al.*, (2017) for filled grains per panicle and 1000-grain weight, Abebe *et al.* (2017) for chaffy grains per panicle and Satyanarayana *et al.* (2005) for spikelet fertility.

Table 1. ANOVA for BC₂F₂ population derived from *O. sativa* (BPT5204) X *O. rufipogon* for yield and its contributing characters in rice

Source of variation	df	DFF	PH	PL	TT	PT	FGP	CGP	SF	TW	GYP
Blocks (Ignoring treatments)	4	117.2 *	603.8 ***	26.51 *	38.60	39.02 **	22302 ***	163.9 *	110.62 ***	48.47 *	349.3 ***
Blocks (Eliminating treatments)	4	22.9	3	3.11	32.57	0.31	371	78.8	13.08	2.20	5.65
Treatments (Eliminating blocks)	191	59.7	164.4 ***	5.67	36.16	27.23 *	5797 **	421.4 **	99.33 ***	10.65	238.8 ***
Treatment (Ignoring blocks)	191	61.7	177 ***	6.17	36.28	28.04 **	6256 **	423.2 **	101.38 ***	11.62	246.03 ***
Treatments	189	59.0	157 ***	5.73	36.24	27.01 *	6299 **	423.6 **	101.19 ***	11.48	248.31 ***
Treatments vs checks	1	7.4	3292 ***	90.00 **	41.44	249.46 ***	2033 *	551.2 **	185.08 ***	36.02 *	42.79 *
Checks	1	618.9 **	760.7 ***	4.99	38.30	0.31	2382 *	215.3 *	52.08 **	13.67	18.63
Residuals	4	16.9	3	1.81	25.77	2.06	229	13	1.97	4.54	5.35
Control treatment means		7.20	2.88	2.36	8.91	2.52	26.56	6.32	2.46	3.74	4.06
Two test treatments (Same block)		16.11	6.44	5.28	19.93	5.64	59.40	14.13	5.50	8.36	9.08
Two test treatments (Different blocks)		19.74	7.88	6.47	24.41	6.90	72.76	17.31	6.74	10.24	11.12
A test treatment and A control treatment		14.41	5.76	4.72	17.82	5.04	53.13	12.64	4.92	7.48	8.12

DFF: Days to 50% Flowering, **PH:** Plant Height, **PL:** Panicle Length, **TT:** Total no. of Tillers, **PT:** Productive Tillers, **FGP:** Filled Grains per Panicle, **CGP:** Chaffy Grains per Panicle, **SF:** Spikelet Fertility, **TW:** Test Weight, **GYP:** Grain Yield per Plant

* Significant at 5%; ** Significant at 1%; *** Significant at 0.1%

Table 2. Descriptive Statistics for yield and its contributing characters in BC₂F₂ population of *O. sativa* (BPT5204) X *O. rufipogon*

Characters	Variability			Coefficient of variation		Heritability (%) (Broad sense)	GAM 5%
	Min	Max	Mean	GCV (%)	PCV (%)		
DFF	110.00	135.00	119.60	5.42	6.42	71.43	9.46
PH	61.00	125.00	86.19	14.55	14.68	98.29	29.77
PL	16.67	27.50	21.80	9.13	11.04	68.35	15.57
TT	3.00	40.00	14.17	22.97	42.72	28.90	25.47
PT	2.00	34.00	12.71	39.93	41.55	92.36	79.18
FGP	40.50	443.5	209.40	37.31	38.00	96.36	75.56
CGP	0.00	150.00	28.17	71.18	72.30	96.93	93.23
SF	21.25	100	87.13	11.45	11.56	98.05	23.40
TW	10.29	38.73	15.48	17.10	21.99	60.46	27.43
GYP	3.10	97.78	27.96	55.58	56.19	97.84	91.42

DFF: Days to 50% Flowering, **PH:** Plant Height, **PL:** Panicle Length, **TT:** Total no. of Tillers, **PT:** Productive Tillers, **FGP:** Filled Grains per Panicle, **CGP:** Chaffy Grains per Panicle, **SF:** Spikelet Fertility, **TW:** Test Weight, **GYP:** Grain Yield per Plant

PCV, GCV & GA Scales: >10-Low; 10-20-Moderate; >20-High.

Heritability Scales (Broad sense): Upto 30-Low; 30-60: Moderate, >60-High.

A perusal of genetic parameters *viz.*, genotypic and phenotypic coefficient of variation revealed less influence of environment on the characters under study. Therefore, response to direct selection may be effective in improving these traits. All the characters under study except days to 50 % flowering, panicle length and total number of tillers per plant exhibited high heritability coupled with high genetic advance as per cent of mean which indicated the preponderance of additive gene action in controlling these traits. Hence direct selection of these characters would be effective in improving the seed yield.

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EFFECT OF DIFFERENT DRIP IRRIGATION LEVELS ON YIELD ATTRIBUTES OF COLOURED CAPSICUM HYBRIDS (*Capsicum annuum* var. *grossum* L.) UNDER SHADE NET

B. KIRUTHIGA, K. AVIL KUMAR, K. SREENIVASA KUMAR and A. SRINIVAS

Water Technology Centre, College of Agriculture

Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad - 500030

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Capsicum is also known as bell pepper or sweet pepper or *shimla mirchi* which is a cool season tropical crop, belongs to the family Solanaceae, and is native of South and Central America. Fruits of *Shimla mirchi* are large (usually bell shaped; hence called bell pepper) and non-pungent (hence also called sweet pepper). The term *Shimla mirchi* originated because probably it was first cultivated in Shimla region (temperate climate), which was suitable for its cultivation. It attained a status of high value crop in India in recent years, occupying an area of 46 thousand hectares, producing 327 thousand metric tons.

Capsicum varieties may occur in many shapes and colours. Capsaicin is the main chemical content in sweet pepper. It is rich in carbohydrates, Vitamin A (8493 IU), Vitamin C (283 mg) and minerals like Calcium (13.4 mg), Magnesium (14.9 mg) Phosphorus (28.3 mg) and Potassium, (263.7 mg) per 100 g fresh weight. The mature fruits (green, red and yellow) of sweet pepper are eaten raw or widely used in stuffings, bakings, pizza, burger preparations, spices and as external medicine.

Water is the vital source for crop production and is the most limiting factor in Indian agricultural scenario. Though India has the largest irrigation network, the irrigation efficiency achieved is not more than 40 per cent. Rational use of irrigation water is important for increasing water productivity as the water is costly and a scarce resource. This can be achieved by advanced method of irrigation like micro irrigation particularly drip irrigation method which is most efficient when coupled with other improved management practices.

To obtain good quality produce, shade nets can be commercially exploited for successful year round

cultivation of high value thermo sensitive crops like sweet pepper. Shade nets are perforated plastic materials used to cut down the solar radiation and prevent scorching or wilting of leaves as result of temperature increase with in leaf tissue from strong sunlight.

Optimization of water to be applied to crops is essential in irrigation system. Yields of crops are adversely affected either with excess or inadequate water supply. Yields can be considerably increased by adopting proper scheduling of water is essential. Irrigation scheduling is the process by which an irrigator/ farmer determines the timing and quantity of water to be applied to the crops. There are only few studies on irrigation requirement and economic aspects of capsicum production. To increase the yield potential of capsicum, the present study was initiated to assess the effect of drip irrigation levels on growth and yield of coloured capsicum hybrids under shade net.

The experiment was carried out at Horticultural farm, College of Agriculture, Rajendranagar, Hyderabad in a shadenet during *rabi*, 2018-19. The farm is geographically situated in the Southern Telangana Zone at 17°19'11" N latitude and 78°24'58" E longitude at an altitude of 542.3 m above mean sea level.

The experiment was conducted in a split plot design with four drip irrigation levels viz., drip irrigation at 0.4 Epan (I_1), drip irrigation at 0.6 Epan (I_2), drip irrigation at 0.8 Epan (I_3), drip irrigation at 1.0 Epan (I_4) as main treatments and three capsicum hybrids viz., Indra (V_1), Orabelle (V_2), Bomby (V_3) as sub treatment replicated thrice. The recommended dose of (RD) nutrients (100:80:60 kg N:P₂O₅:K₂O ha⁻¹) and the

spacing (45 cm × 40 cm) adopted for the experimental soil was sandy loam in texture, slightly alkaline in reaction (pH=7.8), nonsaline (EC=0.31 dS m⁻¹), low in organic carbon (0.2%), low in available nitrogen (145.51 kg ha⁻¹), medium in available phosphorus (47.15 kg ha⁻¹) and low in available potassium (156.7 kg ha⁻¹). Rainfall of 127.4 mm was received during the entire crop growth period. The mean weekly maximum and minimum temperature ranged from 30.8°C to 14.4°C and 19.9°C to 8.7°C respectively.

Drip irrigation was scheduled at 0.4, 0.6, 0.8 and 1.0 Epan for different treatments during the entire crop growth period. The entire dose of phosphorus was applied to soil as basal whereas nitrogen and potassium were applied through fertigation at 3 days interval through venturi system. Urea and Sulphate of potash were the source of N and K₂O fertilizers. Shade net colour was green with 50% shade and tape type drip with lateral spacing, emitter spacing and drip discharge rate of 7.6 m x 0.9 m, 0.6 m, 0.4 m and 4 L h⁻¹, respectively.

Significant variations in capsicum yield and yield attributes were observed due to different drip irrigation levels and hybrids. However, there was no interaction effect between drip irrigation levels and hybrids studied on these parameters.

The average fruit length (9.8 cm) of capsicum was significantly higher with drip irrigation scheduled at 1.0 Epan (I₄) than at 0.8 Epan, 0.6 Epan and 0.4 Epan. This could be attributed to availability of soil moisture in sufficient range with higher uptake of nutrients which possibly led to enhanced photosynthetic area, dry matter production and finally increased fruit length and diameter. Drip irrigation scheduled at 0.4 Epan (I₁) recorded significantly lower average fruit length (8.4 cm) and diameter (6.0 cm). Similar findings were also reported by Sezen *et al.*, (2011), Khalkho (2013), Choudhary and Bhambri (2012) in bell pepper. Higher fruit length (9.4 cm) and diameter (6.9 cm) was noticed with capsicum hybrid Bomby (V₃) which was significantly higher than Orobelle (9.1 cm and 6.6 cm) and Indra (8.9 cm and 6.4 cm). This could be due to higher uptake of nutrients and higher leaf area which build up sufficient photosynthates enabling the increase in length of fruit in that hybrid. This is in concordance to the results of Biwalker *et al.* (2015).

Significantly higher pericarp thickness (5.1 mm) was obtained with drip irrigation scheduled at 1.0 Epan over drip irrigation scheduled at 0.4 Epan (4.7 mm) and was on par with 0.8 Epan (5 mm) and 0.6 Epan (4.9 mm). The fruit assimilate partitioning capacity at favourable moisture conditions might have resulted in formation of higher thickness of fruit pericarp. Similar results were also reported by Choudhary and Bhambri, (2012) and Biwalker (2015) in capsicum. Whereas lower pericarp thickness observed with 0.4 Epan might be due to pronounced water deficit during the reproductive phase leading to unfavourable plant water relation and fruit development. Similar findings were also reported by Dagdelon (2004) in bell pepper.

Among different capsicum hybrids, significantly higher pericarp thickness (5.1 mm) was noticed with Bomby than Indra and was on par with Orobelle (4.9 mm). Significantly lower pericarp thickness (4.6 mm) observed with Indra. Pericarp thickness (4.94 mm) of Orobelle(V₂) was significantly superior over Indra (V₁). Similar findings were also reported by Biwalker (2015) in bell pepper.

Significantly higher number of fruits plant⁻¹ (13.6) of capsicum was obtained with drip irrigation scheduled at 1.0 Epan (I₄) than rest of the drip irrigation schedules as a result of favourable soil moisture regimes and nutrient uptake at vegetative growth which led to higher dry matter accumulation and proper translocation of food materials to the fruits resulting in increased physiological activities and fruit bearing nodes, less flower and fruit dropping. The results were in accordance with Salunkhe (2017), Choudhary and Bhambri (2012) in capsicum and Mahajan and Singh (2006) in tomato.

Whereas the significantly lower number of fruits plant⁻¹ observed at low level of drip irrigation i.e, 0.4 Epan (9.3), 0.6 Epan (I₂), 0.8 Epan (I₃) and 1.0 Epan (I₄) might be observed due to accumulation of ABA and increased level of ethylene resulted under moisture stress and abscission of flowers thereby resulting in less number of fruits per plant. Similar observations were reported by Chartzoulakis *et al.* (1997) and Hegde (1988).

Among the hybrids, Indra (14.5) recorded significantly higher number of fruits plant⁻¹ than Orobelle(V₂) and Bomby (V₃). Significantly lower number of fruits was observed with Bomby (9.2).

EFFECT OF DIFFERENT DRIP IRRIGATION LEVELS ON YIELD

This might be due to varietal differences, more uptake of nutrients by plant at active reproduction stage and high fruit set percentage because of healthy and vigorous growth characters occurred in Indra.

with drip irrigation at 0.4 Epan was significantly lower. When more nutrient availability, especially near the root zone might have increased the translocation of

Table 1: Yield attributes of capsicum as influenced by different drip irrigation levels and hybrids under shade net.

Treatments	Fruit Length (cm)	Fruit diameter (cm)	Pericarp thickness (mm) weight	Fruits plant ⁻¹ (no.)	Average fruit (g fruit ⁻¹)	Fruit yield (kg plant ⁻¹)
Main – (Irrigation levels)						
I ₁ : Drip irrigation at 0.4 Epan	8.4	6.0	4.7	9.3	71.1	0.73
I ₂ : Drip irrigation at 0.6 Epan	8.9	6.3	4.9	10.7	75.3	0.92
I ₃ : Drip irrigation at 0.8 Epan	9.3	6.9	5.0	12.5	83.2	1.08
I ₄ : Drip irrigation at 1.0 Epan	9.8	7.5	5.1	13.6	91.7	1.27
SEm ±	0.0	0.1	0.1	0.2	2.6	0.02
CD (P=0.05)	0.1	0.2	0.3	0.8	9.0	0.08
Sub – (Hybrids)						
V ₁ : Indra	8.9	6.4	4.6	14.5	70.9	1.07
V ₂ : Orobelle	9.1	6.6	4.9	10.8	79.6	1.00
V ₃ : Bomby	9.4	6.9	5.1	9.2	90.4	0.92
SEm ±	0.0	0.0	0.1	0.1	1.8	0.02
CD (P=0.05)	0.1	0.1	0.2	0.4	5.4	0.05
Interaction :Hybrids at same level of irrigation levels						
SEm ±	0.1	0.1	0.1	0.3	3.6	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Irrigation levels at same or different hybrids						
SEm ±	0.1	0.1	0.1	0.3	3.9	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS

Note : Fruit length, diameter, pericarp thickness, fruit weight of capsicum were recorded at 1st, 3rd and 5th pickings and average value as picking wise data was given.

Fruits plant⁻¹ and fruit yield plant⁻¹ were recorded at 1st to 5th pickings and totally presented as average.

The average fruit weight of capsicum was significantly higher (91.7 g fruit⁻¹) with drip irrigation scheduled at 1.0 Epan (I₄) over rest of the treatments and was on par with drip irrigation at 0.8 Epan (83.2 g fruit⁻¹). Drip irrigation at 0.8 Epan (I₃) was significantly higher than 0.4 Epan (I₁) and was at par with drip irrigation at 0.6 Epan. The average fruit weight noticed

photosynthates to storage organ resulting in an increased fruit weight of capsicum under drip irrigation.

Whereas the lower fruit weight noticed with drip irrigation scheduled at 0.4 Epan could be due to lack of optimum soil moisture in the root zone; when soil water deficit in root zone increases, there is loss of

turgidity leading to reduction in average fruit weight as reported by Sezen *et al.* (2011) and Smittle *et al.* (1994).

Among the hybrids, Bomby recorded significantly higher fruit weight (90.4 g) than Orobelle (79.6 g) and Indra (70.9 g). Significantly lower fruit weight was recorded with Indra over rest of the hybrids. This could be due to a high uptake of nutrients and build up of sufficient photosynthates enabling the increase in size of fruits (length and breadth), resulting in the increased fruit weight and volume in Bomby hybrid.

With respect to fruit yield plant⁻¹ drip irrigation at 1.0 Epan (I₄) recorded significantly higher fruit yield plant⁻¹ (1.27 kg) than 0.8 Epan (1.08 kg) and 0.6 Epan (0.92 kg). Significantly lower fruit yield plant⁻¹ (0.73 kg) was recorded with drip irrigation at 0.4 Epan (I₁) over rest of the treatments. More water and nutrient availability, with high level of drip irrigation especially near the root zone might have increased the translocation of photosynthates to storage organ of capsicum resulting in increased fruit number and fruit weight which ultimately increased the yield of the plant.

Fruit yield plant⁻¹ of capsicum differed significantly among different hybrids and was significantly higher (1.07 kg) with Indra (V₁) than Orobelle (1.00 kg) and Bomby (0.92 kg). This might be due to vigorous plant growth which led to more fruit bearing nodes and resulted in higher fruit set percentage per plant in Indra

CONCLUSION

From the present study it can be concluded that all yield parameters with drip irrigation at 1.0 Epan recorded significantly higher than rest of the treatments and among the hybrids, Bomby recorded significantly higher fruit length and diameter, pericarp thickness and average fruit weight than Orobelle and Indra, but significantly higher fruit yield plant⁻¹ was associated with Indra hybrid.

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COST, RETURNS AND PROFITABILITY OF GROUNDNUT CULTIVATION IN MAHABOONNAGAR DISTRICT OF TELANGANA STATE

A. JYOTHIRMAI, G.P. SUNANDINI, K. SUHASINI and D. SRINIVASA CHARY

Department of Agriculture Economics, College of Agriculture

Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad - 500030

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Groundnut is the KING of oilseeds and it is botanically known as '*Arachis hypogaea*' and belongs to the family Leguminosae. Groundnut is a cash crop providing income and livelihood to the farmer. It also contributes to nutrition through consumption of pods. The pod contains 48.2% oil, 25.3% protein, 2.1% crude fiber and rich source of calcium, iron and vitamin B complex like thiamine, riboflavin, niacin and vitamin A.

Groundnut constitutes 2.61 percent of the total cropped area and 28.18 percent of the total oil seeds cropped area in Telangana. Mahaboobnagar, Warangal and Nalgonda districts together accounts for 86.66 percent of groundnut area in the state. The groundnut cropped area in Mahaboobnagar district was 0.79 lakh hectares during in 2015-16 as against 0.97 lakh hectares in 2014-15 showing a decrease of 0.18 lakh hectares over previous year.

The study of costs and returns helps in identification of major contributors for cost of cultivation and management of costs for attaining reasonable profits.

The maximum area under groundnut cultivation is concentrated in Mahaboobnagar district of Telangana state therefore; Mahaboobnagar district was selected purposively for the study. Four villages viz. Uppunthala, Penmilla, Kalwakole and Vennacherla from two mandals viz., Peddakothapalli and Uppunntmhala mandals from Mahaboobnagar district were selected purposively on the basis of maximum area under groundnut cultivation as per secondary data obtained from Directorate of Economics and Statistics, Hyderabad. From the selected villages, the list of groundnut cultivators were obtained from the mandal agricultural office of the selected mandals. From each selected village, a sample of forty (40) groundnut cultivators were selected randomly. Thus the final sample consisted of 4 villages and 120 groundnut cultivators from both Peddakothapalli and Uppunntmhala mandals.

The data were collected by personal interview by using a pre-tested schedules for groundnut cultivators. Simple statistical tools such as sum, average, percentage, ratios were worked out. For working out

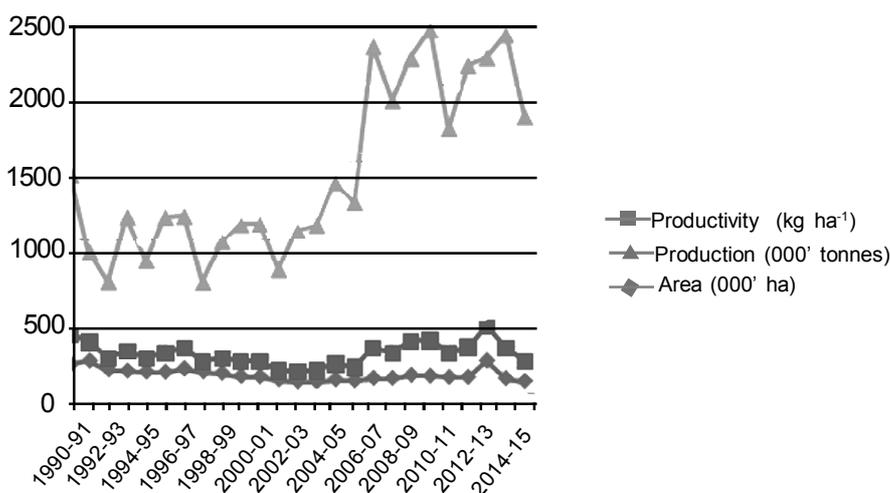


Fig 1 : Area, Production and Productivity of groundnut crop in Mahaboobnagar district (2000-01 to 2015-16)

cost of production, cost concepts viz., cost-A1, cost-A2, cost-B1, cost-B2, cost-C1, cost-C2 and cost-C3 were used.

Costs and returns of groundnut cultivation of average farmers according to farm size

Costs and returns are very much essential to decide the profitability of crop production in agriculture.

Table 1: Cost of cultivation of groundnut of average farmers according to different farm sizes (Rs. ha⁻¹)

	Particulars	Marginal farmers	Small farmers	Large farmers	Pooled farmers
Cost A1	Hired human labour	20665.01	21088.20	21990.10	21247.67
	Bullock labour value	1459.45	1700.00	1056.05	1405.16
	Machinery labour value	9640.00	9775.00	10721.00	10045.33
	Value of seed	18965.00	19131.80	19892.70	19329.83
	Value of PPCs	1950.00	2229.20	2473.00	2217.40
	Value of manure	3445.94	4457.14	4162.16	4021.74
	Value of fertilizers	8534.45	8713.78	8821.47	8689.90
	Irrigation charges	113.51	137.14	162.16	137.60
	Miscellaneous expenses	1150.00	1257.00	1230.00	1212.33
	Interest on working capital	4120.20	4280.56	4406.78	4269.18
	Depreciation	725.25	889.20	1096.50	903.65
	Total	70768.81	73658.83	76011.82	73479.82
Cost A2	Cost A1	70768.81	73658.83	76011.82	73479.82
	Rent paid for leased-in land	0.00	0.00	0.00	0.00
	Total	70768.81	73658.83	76011.82	73479.82
Cost B1	Cost A2	70768.81	73658.83	76011.82	73479.82
	Interest on value of owned fixed capital	1186.775	1219.62	1259.65	1222.01
	Total	71955.58	74878.45	77271.47	74701.83
Cost B2	Cost B1	71955.58	74878.45	77271.47	74701.83
	Rental value of owned and leased-in land	11142.50	11307.00	11500.00	11316.50
	Total	83098.08	86185.45	88771.47	86018.33
Cost C1	Cost B1	71955.58	74878.45	77271.47	74701.83
	Imputed value of family labour	2456.30	2690.10	2305.70	2484.03
	Total	74411.88	77568.55	79577.17	77185.87
Cost C2	Cost B2	83098.08	86185.45	88771.47	86018.33
	Imputed value of family labour	2456.30	2690.10	2305.70	2484.03
	Total	85554.38	88875.55	91077.17	88502.37
Cost C3	Cost C2	85554.38	88875.55	91077.17	88502.37
	Value of management input (10% of total cost)	8555.43	8887.55	9107.71	8850.23
	Total	94109.82	97763.10	100184.90	97352.60

COST, RETURNS AND PROFITABILITY OF GROUNDNUT CULTIVATION

Apart from this production costs plays a vital role in the decision making and differ from season to season, year to year even for the same farmer.

The per hectare cost of cultivation of groundnut of average farmers according to different farm size had been presented in the Table 1.

The tabular analysis revealed that the per hectare cost of cultivation ranged from Rs.94109.82 for marginal farmers to Rs.100184.9 for large farmers. It also had been noticed that on small and pooled sample farmers the cost of cultivation was Rs.97763.1 and Rs.97352.6 respectively. It had been observed that there was a considerable difference in cost of cultivation between the large and marginal farmers than between large and small farmers. Choudary *et al.*, (2017) reported a cost of cultivation of Rs. 49,908.07, 51,760 and 49,633.91 for small, medium and large size holdings in *kharif* groundnut at Gujarat. Kurrery and Jain (2018) also reported an increase in cost of cultivation with increase in size of land holding.

From the Table 1, it was observed that rental value of owned land accounts for 11.62% of the total cost (cost C3) for the pooled farmers.

On examining the cost A1, it is evident that hired human labour charges were found to be the highest compared to all other variable costs, irrespective of the farm size followed by seed cost. Both these costs account for 55.99% of the cost A1 for marginal farmers and 55.10% in case of large farmers.

On examining the imputed value of family labour, there was no significant variation among different farm sizes ranging from 2.61% to 2.30% from marginal to large farmers of the total cost (cost C3).

Table 3 revealed that both gross returns and net returns vary directly with the farm size. The gross returns per hectare ranged from Rs.103362.30 for marginal farmers to Rs.118519.80 for large farmers. It was also observed that net returns per hectare of groundnut ranged from Rs.9252.47 for marginal farmers to Rs. 18334.91 for large farmers.

Table 2: Cost of cultivation (Rs ha⁻¹ (as per cost concepts)

Cost component	Marginal farmers	Small farmers	Large farmers	Pooled farmers
Cost A1	70768.81 (75.19%)	73658.83 (75.34%)	76011.82 (75.87%)	73479.82 (75.47%)
Cost A2	70768.81 (75.19%)	73658.83 (75.34%)	76011.82 (75.87%)	73479.82 (75.47%)
Cost B1	71955.58 (76.45%)	74878.45 (76.59%)	77271.47 (77.12%)	74701.83 (76.73%)
Cost B2	83098.08 (88.29%)	86185.45 (88.15%)	88771.47 (88.60%)	86018.33 (88.35%)
Cost C1	74411.88 (79.06%)	77568.55 (79.34%)	79577.17 (79.43%)	77185.87 (79.28%)
Cost C2	85554.38 (90.90%)	88875.55 (90.90%)	91077.17 (90.90%)	88502.37 (90.90%)
Cost C3	94109.82 (100%)	97763.1 (100%)	100184.90 (100%)	97352.6 (100%)

NOTE: Figures in the parenthesis indicate percentage to Cost C3

Table 3. Returns per hectare of groundnut cultivation for average farmers according to different farm size

Farm size	Yield (kg ha ⁻¹)	Gross returns (Rs ha ⁻¹)	Total costs (Rs ha ⁻¹)	Net returns (Rs ha ⁻¹)	B-C ratio	Cost of production (Rs q ⁻¹)
Marginal farmers	2418.24	99088.20	94109.82	4978.37	1.05	4059.00
Small farmers	2514.28	107148.40	97763.10	9385.25	1.09	4049.00
Large farms	2659.45	114276.00	100184.90	14091.09	1.14	3914.00
Pooled farmers	2530.65	106764.60	97352.60	9412.03	1.09	3846.00

The Benefit Cost Ratio (BCR) was also worked out to know the profitability of the groundnut cultivation. The results showed that the BCR was 1.05, 1.09, 1.14 and 1.09 for marginal, small, large and pooled farmers respectively. From the above results, it could be understood that profitability of groundnut cultivation was not appreciable owing to the existing low yields. Pawar *et al.*, (2016) also reported a benefit cost ratio of 1.19, 1.24 and 1.14 for small, medium and large group respectively.

Cost of production of groundnut was also calculated according to the farm size and was presented in table 3. A glance into the table reveals that for the pooled farmers Rs. 3846.00 should be incurred to produce 1 quintal of groundnut. Further it was observed that cost of production had a negative

- Hired human labour charges were found to be highest among all variable costs followed by seed cost in all groups.
- The per hectare total cost of cultivation of the large farmers Rs.100184.90 was almost 1.06 times higher than the Cost C3 of the marginal farmers. This cost difference occurred because of difference in resource position, use of inputs and other management practices.
- The BCR ranged from 1.05 for small farmers to 1.14 for large farmers.

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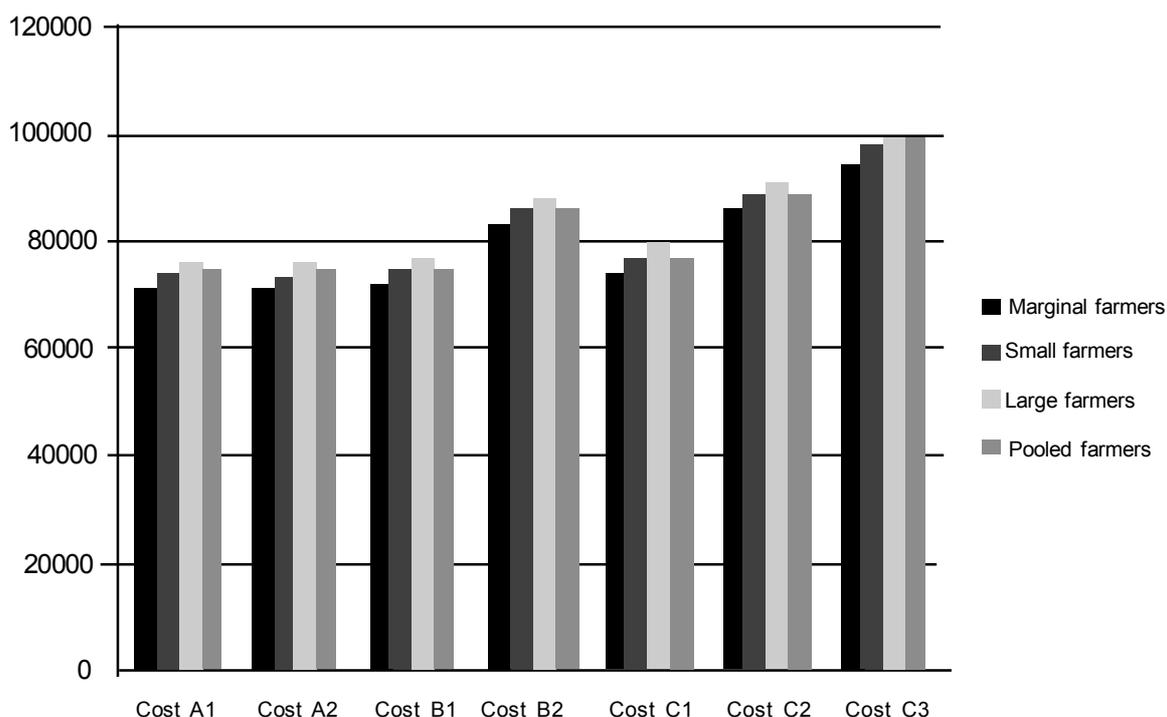


Fig.2 Cost of cultivation of groundnut of average farmers (Rs/ha) as per cost concepts

relationship with the farm size i.e, cost of production decreased with increase in farm size.

- In the study area the total cost of cultivation (Cost C3) ranged from Rs.94109.82 per hectare for marginal farmers to Rs.100849.9 per hectare for large farmers indicated that the per hectare cost of cultivation increased with the increase in the farm size.

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