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Genetic Gain and Productivity Trend Analysis for the Yield of Rice Varieties in Central India

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Abstract

The genetic gains and productivity trends were estimated for rice varieties developed by Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, India from 1905 to 2021 to assess the improvement in rice breeding programme. During this period (categorized into three different phases - 1, 2 and 3), 90 rice varieties were developed. Twenty-four varieties that became popular in different phases (Seven popular landraces from Phase 1, six varieties from Phase 2 and 11 varieties from Phase 3) were selected and evaluated for yield over five consecutive years (2017 to 2021) under replicated trials. The study revealed highest genetic gain of 1.50% for yield in the varieties that were released in Phase 2 with a yield enhancement of about 51 kg ha^{-1} $year^{-1}$, followed by a genetic gain of 1.03% (43 kg ha^{-1} $year^{-1}$) during Phase 3 and least genetic gain of 0.159% (4 kg ha^{-1} $year^{-1}$) in Phase 1. This increase seems to be a result of planned and strategic research in crop improvement coupled with improved agronomic practices.

Keywords: Genetic gains, IGKV, productivity trend, rice breeding, rice varieties.

Introduction

Rice is the main staple food crop of India with more than 65 per cent of the population depending on it for their livelihood (Singh and Singh, 2020). The major contributors for rice production in India during the year 2018-19 are West Bengal (13.79%), Uttar Pradesh (13.34%), Andhra Pradesh with Telangana (12.84%), Punjab (11.01%), Odisha (6.28%), Chhattisgarh (5.61%), Tamil Nadu (5.54%), Bihar (5.19%), Assam (4.41%), Haryana (3.88%) and Madhya Pradesh (3.86%). In India, rice breeding has made significant contributions in ensuring national food security and supplying of food to its burgeoning 1.35 billion population. India is also a major global exporter of Basmati and Non-Basmati quality of rice. Apart from having a large geographical area (328 m ha), its varied agro-ecological climatic conditions and diverse soil types contribute to its current global status in rice area and production. Further, this achievement is also due to the continuous efforts of breeders and collaborating scientists, appropriate policies and above all, the efforts of millions of rice farmers from diverse parts of the country. Rice breeding in India has significantly contributed towards improving the socio-economic status by ensuring food security along with the commerce of the country. The rice varieties developed from Andhra Pradesh is occupying more then 50% area in eastern Indian states (Reddy *et al.,* 2022).

Indira Gandhi Krishi Vishwavidyalaya (IGKV) was established in 1987 in Raipur city of the Chhattisgarh State of India. It is one of the premier institutes working on rice breeding in the country. It has a dynamic rice-breeding program dedicated to improving rice genotypes for grain yield, nutritional quality, and other traits of economic value along with replicated multi-location testing across different rice growing environments towards the release of potential and stable varieties for commercial cultivation. Rice is also the main food crop of the Chhattisgarh state, and most of its economy depends on rice production and procurement.

It is anticipated that climate change, mainly temperature rise will have a direct impact on the yield of main crops like rice. In this scenario, rice will have a severe impact due to its high-water requirement (Zhao *et al.,* 2017). Further, because of tremendous population growth, consumption of rice is projected to increase to more than 578 million tons and the average consumption is estimated to increase by 1 kg to reach 55 kg per year by 2028. However, the area utilized for rice production is estimated to increase by only 1% (Anonymous, 2019).

Therefore, enhancement in rice production can only be achieved by yield improvement coupled with superior agronomic practices. Therefore, breeding programs must aim to develop new climate-resilient varieties having higher yields under varied climatic conditions and help to get over the evident threats to food security. Yield potential in rice is estimated to be 15–16 t/ha and the yields of 10 t/ha could be realized under assured irrigation (~20 mha) and rainfed shallow lowland (11 mha) ecosystems. The yield gap of approximately 6 t/ha is therefore, needed to be reduced on priority through appropriate technical and policy interventions to sustain the demands of the burgeoning population (Muralidharan *et al.,* 2019). The yield gaps can be enhanced with the introgression of genes for biotic stresses like BLB and blasts (Aleena *et al*., 2023).

Genetic gain, a measure of performance enhancement, achieved through selection (Xu *et al.,* 2017) with respect to important traits, including yield results in improved profitability and sustainability and hence, is crucial for the adoption of new varieties at the field level by the rice farmers.

Estimate of genetic gain realized for yield has been assessed in plant breeding programs of maize and Canola to quantify the progress made in breeding programs by earlier workers (Crespo-Herrera *et al.,* 2018, Laidig *et al.,* 2014). In this context, the assessment of productivity trend of popular varieties developed through breeding programs was undertaken to understand the level of genetic gains achieved in rice breeding programs of IGKV, Raipur.

Materials and Methods

Details of Experiment

The present study was conducted at IGKV, Raipur, Chhattisgarh, India (Lat 21^{0}25'14"N, long 81^{0}62'96"E, 298 m asl). A set of 24 rice varieties released since 1905 were evaluated for grain yield and other ancillary characters for five consecutive years from 2017 to 2021. The study was undertaken during the *kharif* season in two replications under Randomized Block Design.

Genotypes

Twenty four varieties released during different years were categorized into three different phases. Phase 1 represents the pre-green revolution era, while Phase 2 is the period between 1987-2005 and Phase 3 represents the period between 2005-2021. During Phase 1, seven landraces, namely Bhondu No. 11, Parewa No. 22, Cross 116, Laloo 14, Madhuri, Safri-17 and Pandri Luchai were selected for the study. In Phase 2, six varieties, namely, Kranti, Mahamaya, Purnima, Danteshwari, Bamleshwari and Indira

Sugandhit Dhan-1 and under Phase 3, 11 popular varieties, namely, Samleshwari, Chandrahasini, Karma Mahsuri, Rajeshwari, Durgeshwari, Indira Barani Dhan-1, Maheshwari, Indira Aerobic-1, Chhattisgarh Sugandhit Bhog, Chhattisgarh Devbhog and CG Dhan 1919 were selected for evaluation (**Table 1**). These varieties were sown for five consecutive years from 2017 to 2022 in Randomized Complete Block Design (RCBD) in two replications using standard agronomic practices at Research Farm of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh.

Statistical analysis

Agronomic data of grain yield were separately analyzed for each year using the mixed model:

$$y_{ijklm} = \mu + g_i + s_j + gs_{ij} + b_k + \varepsilon_{ijk(1)}$$

Where y_{ijk} is the grain yield measurement for the ith genotype in the jth year and kth complete block;

μ is the overall mean; g_i is the fixed effect of genotype; s_j is the random effect of the specific season;

gs_{ij} is the random effect of the interaction between the genotype and the specific season;

b_k is the random effect of the complete block, also referred to as replicate; and ε_{ijkl} is the residual error.

All the random effects were assumed identically and independently distributed (i.i.d).

Table 1: Mean yield of varieties released by IGKV, Raipur

S. No.	Rice Varieties	Year of release	Yield (kg/ha)
1.	Bhondu No 11	1913	2101.50
2.	Parewa No 22	1923	2165.45
3.	Cross116	1942	2294.93
4.	Laloo 14	1964	2550.82
5.	Madhuri	1965	3149.55
6.	Safri-17	1966	3096.46
7.	Pandri Luchai	1966	3227.98
8.	Kranti	1987	2905.42
9.	Mahamaya	1996	4297.58
10.	Purnima	1997	2985.55
11.	Danteshwari	2001	2931.88
12.	Bamleshwari	2001	4203.14
13.	Indira Sugandhit Dhan-1	2005	3316.44
14.	Samleshwari	2007	3807.04
15.	Chandrahasini	2007	3532.23
16.	Karma Mahsuri	2008	4215.16
17.	Rajeshwari (IGKV, R1)	2011	4486.82
18.	Durgeshwari (IGKV, R2)	2011	3483.67
19.	Indira Barani Dhan 1	2012	3886.82
20.	Maheshwari (IGKV, R1244)	2012	3666.40
21.	Indira Aerobic-1	2015	4390.93
22.	Chhattisgarh Sugandhit Bhog	2017	4494.69
23	Chhattisgarh Devbhog	2019	4701.52
24.	CG Dhan 1919	2021	5654.78

Software used

Analysis for the current study was done using the R statistical programming language and environment utilizing the packages l me 4 and ls means through R version 3.4.3. (Lenth, 2016).

Results and Discussions

The study was conducted to analyze the genetic gains of the developed varieties and their trends in the productivity of major rice varieties. The period of 100 years of rice research in IGKV has been divided into three phases *i.e.,* Phase I (pre-green revolution era, prior to 1987), Phase II (after the establishment of Indira Gandhi Krishi Vishwavidyalaya, Raipur in the year 1987 up to 2005) and Phase III (after 2005 to 2021). The mean yield data of varieties released by IGKV are provided in **Table 1**. A total of 24 rice varieties were released during the three phases, Phase 1 (seven varieties), Phase 2 (six varieties), and Phase 3 (11 varieties) and their mean yield in kg/ ha has been provided (**Tables 2 to 4**).

Table 2: Yield of rice varieties developed during Phase 1 (1913 to 1966)

S. No.	Name of the variety	Year of release	Yield (kg/ha)
1.	Bhondu No 11	1913	2101.50
2.	Parewa No 22	1923	2165.45
3.	Cross116	1942	2294.93
4.	Laloo 14	1964	2550.82
5.	Madhuri	1965	3149.55
6.	Safri-17	1966	3096.46
7.	Pandri Luchai	1966	3227.98

Table 3: Yield of rice varieties developed during Phase 2 (1987 to 2005)

S. No.	Name of the variety	Year of release	Yield (kg/ha)
1.	Kranti	1987	2905.42
2.	Mahamaya	1996	4297.58
3.	Purnima	1997	2985.55
4.	Danteshwari	2001	2931.88
5.	Bamleshwari	2001	4203.14
6.	Indira Sugandhit Dhan-1	2005	3316.44

Table 4: Yield of rice varieties developed during Phase 3 (2005 to 2021)

S. No.	Name of the variety	Year of release	Yield ($kgha^{-1}$)
1.	Samleshwari	2007	3807.04
2.	Chandrahasini	2007	3532.23
3.	Karma Mahsuri	2008	4215.16
4.	Rajeshwari (IGKV, R1)	2011	4486.82
5.	Durgeshwari (IGKV, R2)	2011	3483.67
6.	Indira Barani Dhan 1	2012	3886.82
7.	Maheshwari (IGKV, R1244)	2012	3666.4
8.	Indira Aerobic-1	2015	4390.93
9.	Chhattisgarh Sugandhit Bhog	2017	4494.69
10.	Chhattisgarh Devbhog	2019	4701.52
11.	CG Dhan 1919	2021	5654.78

Genetic trend estimates for 24 rice varieties

Genetic trend estimates of variety mean yields for 24 varieties of Raipur, Chhattisgarh have been presented in **Table 5**. A considerable variation in yield *per se* among the varieties released during the three phases studied was observed. The multi-year evaluation of rice varieties and their yield data were subjected to analyze the genetic gains and productivity trends in different eras of the rice breeding program at IGKV. A high level of genetic gain for yield was found for the varieties that were released in Phase 2 which was 1.50% along with a yield increase of about 51 kg ha^{-1} $year^{-1}$. During Phase 3, a genetic gain of 1.03% (43 kg ha^{-1} $year^{-1}$) and the least genetic gain of 0.159% (4 kg ha^{-1} $year^{-1}$) in Phase 1 was observed.

Table 5: Genetic Trend Model - Estimate of variety mean yields for IGKV released varieties

Phases	Number of varieties	Baseline yield $\pm$ Standard error	Increase of yield (kg ha^{-1} $year^{-1}$)	Yield gain ($year^{-1}$)	Model R squared
Phase I	7	2655 $\pm$ 187.2	4.23 $\pm$ 0.25	0.159%	0.912
Phase II	6	3440.0 $\pm$ 279.7	51.63 $\pm$ 9.32	1.50%	0.020
Phase III	11	4210.9 $\pm$ 258.5	43.68 $\pm$ 8.58	1.03%	0.485

Productivity trends during three phases

As shown in **Figure 1**, the productivity trend of studied 24 rice varieties shows a regression R^2 value of 0.773 and an incremental yield improvement throughout the released years. During the Phase 1 study of seven varieties (pre-green revolution era) **(Figure 2)**, the productivity trend shows a regression R^2 value of 0.912 with a linear yield increment. In the present study, **Figure 3.** showed a regression R^2 value of 0.020 with a linear increment in yield whereas a regression R^2 value of 0.485 with a linear yield increment is visible in **Figure 4**. Both figures (**Figures 3 and 4**) show productivity trends of rice varieties developed after the establishment of the University in 1987. **Figures 1-4** shows, the IGKV-released varieties over the past 100 years had an increased genetic trend. The regression constant for the baseline grain yield is highest for Phase 1 followed by Phase 3 and least for Phase 2. Whereas an increased yield indicated by the slope of the regression lines was found to be higher in Phase 1 as compared to Phases 2 and 3.

Genetic trend estimates for 24 varieties

The high degree of genetic gain for yield was found in the varieties that were released in Phase 2 (varieties released from 1987 to 2005) which was 1.50% with a yield improvement of about 51 kg ha^{-1} $year^{-1}$. This is due to the introduction of the dwarfing gene(s) in varieties which were high-yielding and fertilizer responsive, whereas during the pre-green revolution era, rice improvement was done mainly through selection from traditional varieties to release new, locally suitable cultivars.

In the case of rice, genetic gain analysis was conducted very rarely, mainly in Asia where rice is the major food crop. A study in Southeast Asia was conducted by Peng and Khush (2003) at IRRI, Philippines in 1996 and they found 1% yield (75-81 kg ha^{-1}) increase per year. While Breseghello *et al*., (2011) in Brazil analyzed genetic gain for rice breeding of upland for 25 years and found that there was no significant yield improvement annually between 1984 and 1992. Whereas 15.7 kg ha^{-1} $year^{-1}$ (0.53%) yield increased between 1992 and 2002; and approximately three times from 2002 to 2009 at a yield gain of 45.0 kg ha^{-1} $year^{-1}$ (1.44%). Kumar *et al.,* (2020) in India reported genetic gains in rice cultivars cultivated from 2005 to 2014 with 0.68–1.9% for grain yield under different levels of moisture stress regimes.

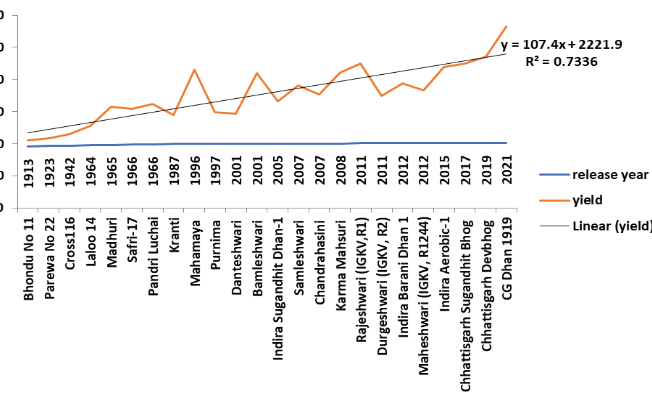

Figure 1: Productivity trend and regression line over the years

Similar results were reported after an assessment of genetic gain performed in a study of maize crop by Crespo-Herrera *et al.,* (2018) who reported a grain yield of 38 kg ha^{-1} $year^{-1}$ (1.8%) under marginal condition, while a yield of 57 kg ha^{-1} $year^{-1}$ (1.4%) in average productivity condition and over all the conditions, observed yield increase was 48 kg ha^{-1} $year^{-1}$ (1.6%). Laidig *et al.,* (2014) in Germany assessed the genetic gain for 12 different crop varieties developed in 30 years by various crop breeding programs. They found yield improvement in all the crops for improved varieties, the highest gain was observed in Winter canola or winter oil seed rape (1.86% yearly) and lowest in Italian ryegrass (0.16% yearly).

Productivity trends during three phases

Comparing the Productivity trend of IGKV-released varieties and estimated genetic gain during the

Phase 1 study, The R^2 value of 0.912 with genetic gain in yield was observed to be about 0.159% (**Figure 2 and Table 5**), where the rice improvement was based on the selection of locally popular landraces. Whereas, during post green revolution era, the hybridization-led crop improvement research was initiated and the development of semi-dwarf, nutrient-responsive cultivars, the yield genetic gains were found to be around 1.5% during Phase 2 with a regression R^2 value of 0.020. During Phase 3 the annual genetic gain comes to be around 1.03% in terms of yield/ year with an R^2 value of 0.485. During post green revolution phase, the rice breeding program mainly focused on the incorporation of polygenes for pest resistance and tolerance to abiotic stresses such as moisture stress by utilizing conventional and molecular breeding approaches, which leads to the development of climate-resilient crop varieties. Varietal development and pyramiding of high yield and superior grain quality traits were also emphasized along with nutritional quality traits.

The yield trends of varieties developed and released by IGKV after its establishment in 1987 is depicted in **Figures 3 and 4**. Rice productivity not only witnessed a continuous increase during both the pre- and post-green revolution phases but more importantly the yield gain has been improved day by day. This is an important achievement because rice is cultivated in the *kharif* (wet season) in the Chhattisgarh state of India, and therefore, it is highly vulnerable to erratic rainfall patterns and quantity. But during phase 3 there was a steep decrease in the genetic gain of 0.47% (from 1.50% to 1.03%) suggesting that there is a scope for improvement in the modernization of the breeding program to shorten the breeding cycle and enhance the genetic gain by adopting speed breeding and smart breeding tools and techniques to increase the selection accuracy and experimental reliability.

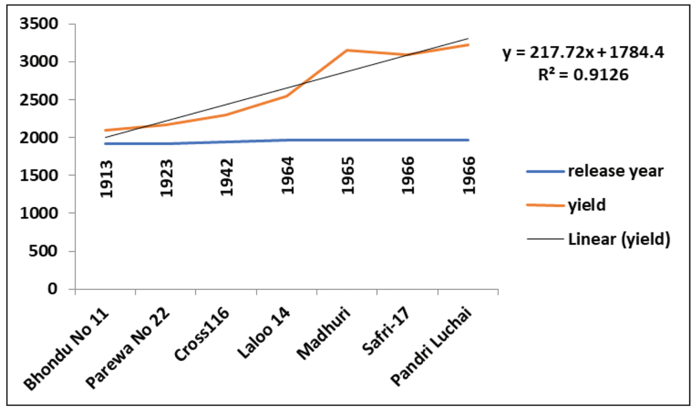

Figure 2: Productivity trend of rice varieties during Phase I (Pre-green revolution)

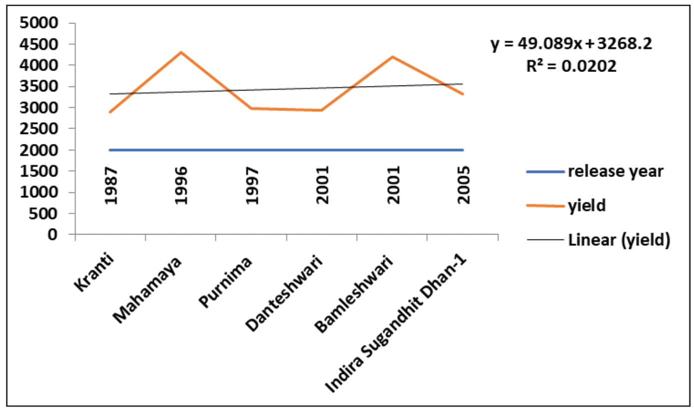

Figure 3: Productivity trend of rice varieties during Phase II (Post green revolution)

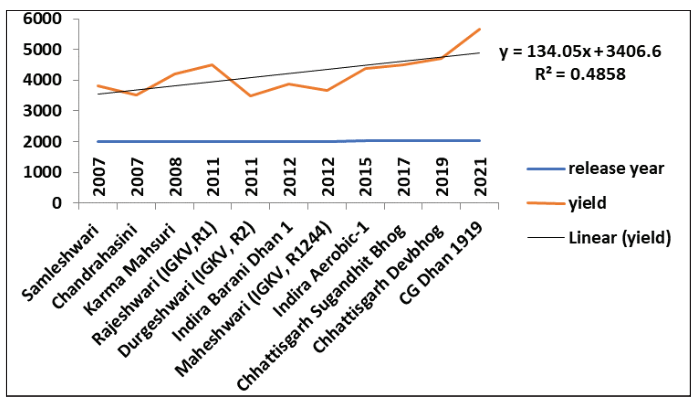

Figure 4: Productivity trend of rice varieties developed during Phase III (after 2005 to 2021)

Analysis of the degree of productivity enhancement in rice varieties since 1911 of the IGKV rice breeding program indicated that there is a consistent increase in productivity from 4 kg ha^{-1} $year^{-1}$ to 51 kg ha^{-1} $year^{-1}$ during all three phases of crop improvement activities. This increase could be due to the planned and applied research in rice improvement and agronomic management practices.

Conclusions

Estimation of genetic gains in terms of yield of the developed varieties to assess the impact of any breeding program through experiments like "Era" studies or historical data sets analysis required to be conducted time to time under multi-location evaluation trials as the varying scenario of climate change is the important impact on rice growing environments. These studies provide directions to the crop improvement programs to plan strategically for the release of enhanced cultivars that could be adopted by the farmers for increased profitability. The assessment of the degree of productivity enhancement of rice varieties since 1911 of the IGKV rice breeding program indicates a consistent increase in productivity from 4 kg ha^{-1} $year^{-1}$ to 51 kg ha^{-1} $year^{-1}$ during three phases of crop improvement activities. This increase seems to be a result of planned and strategic research in crop improvement with improved agronomic practices.

Consumer/market-preferred grain quality characters under multi-environment trials of advanced breeding lines must also be analyzed for the popularization of new varieties. Analysis may provide the targeted genetic gain by breeding programs for planning crossing programs and strategies to achieve objectives with the incorporation of desired variable lines in the breeding programs. Analysis of actual genetic gain at the field level is the critical input, which gives an idea to breeders to make important changes for speeding up the varietal improvement programs while catering to the variable market and consumer preferences. This study will help to decide the investments in different aspects of the breeding program efficiently and in an effective manner. Although a lot of progress has been made in the last decades, the genetic gain from the different crop breeding strategies is plateaued over time and the yield enhancement in present times is contributed more by agronomic interventions.

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Declaration of Competing Interest

The authors declare that there are no known competing interests or personal relationships, which influence the work reported in this paper.

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