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ANALYSIS OF GENOTYPIC AND PHENOTYPIC CORRELATIONS AND PATH COEFFICIENTS IN 40 GENOTYPES OF RAIN-FED UPLAND RICE (*ORYZA SATIVA* L.) IN OYO AND OGUN STATES REGIONS OF NIGERIA

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Abstract: Sustainable rice production in upland habitats depends on achieving higher yields. This study employs correlation and path coefficient analyses to identify essential trait criteria for enhancing rice yield in upland genotypes. The study included two growing seasons using 40 genotypes. Genotypic correlation analysis reveals a robust positive correlation of effective tillering with panicle number and yield. Notably, it shows significant negative correlations with 1000-grain weight and leaf width across diverse locations and cropping seasons. Additionally, the phenotypic estimates underscore a substantial positive correlation between yield and panicle number. Furthermore, the path analysis reveals that panicle number maintains a significantly positive association with yield at the 5% level of significance. Moreover, the analysis of the direct and indirect genotypic effects underscores the significance of culm number, effective tillering, and panicle number, all of which show remarkable and positive correlations with yield, achieving statistical significance at both the 5% and 1% levels. To enhance rice grain yield, a genotype must have an elevated count of pivotal traits per plant, including heightened panicle number, increased panicle length, greater culm number, elongated culm length, a greater number of effective tillers, early flowering initiation, expedited maturation, and augmented leaf length. These characteristics are pivotal determinants contributing significantly to the overall grain yield in rice cultivation and they are instrumental for sustainable rice improvement in the agro-ecology.

Key words: genetic diversity, rice improvement, yield, yield-related traits, genotype by environment interactions.

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Introduction

Rice, one of the oldest and most important sources of energy for the human population, can be traced back to two species, *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice), whereby the species name clearly reveals that rice originates from Africa and Asia. Rice plays a role as a cereal crop worldwide, as several studies have shown (Cheng et al., 2020). According to Nwanze et al. (2006), twenty million farmers around the world are involved in rice cultivation. It is one of the staple foods consumed globally in various forms (Kumar et al., 2020). More than half of the population relies on rice for their daily caloric intake, while approximately one billion households worldwide depend on its cultivation, processing, distribution, and marketing for their livelihoods (Asante et al., 2019). In Nigeria, rice production falls short of meeting consumption demands (Graham Acquaah et al., 2018), which leads to imports and higher prices that disadvantaged individuals find difficult to afford. Chen et al. (2020) have reported an increasing demand for high quality rice in China, potentially impacting the availability of rice grains in countries such as Nigeria that rely on imports, from other countries. Globally, upland rice accounts for 11% of rice grain production and is cultivated across 14 million hectares (Sohrabi et al., 2012). Although the overall percentage of rice production may not appear significant, upland rice is of great importance in tropical areas (Sohrabi et al., 2012). Comparing upland rice to wetland rice, the yield of upland rice is significantly lower. The average yield of wetland rice is around 3.30 tons per hectare, with a potential of 10 tons per hectare under ideal conditions. In contrast, upland rice yields range from 0.46 to 1.50 tons per hectare. To achieve self-sufficiency in rice production and meet the growing demand in regions with low rice yields, there is an urgent need to develop high-yielding upland rice varieties (Mulugeta et al., 2012). Although Nigeria has the potential for large-scale production, the lack of adaptable varieties has been one of its major setbacks. The approaches to generating adaptable varieties were based on the availability of desirable genetic variability for unique and important traits (Sumanth et al., 2017). Upland rice cultivation has gained popularity due to increased genetic variability caused by current high-yielding varieties, scarcity of irrigation water, and the breakdown of resistance genes to emerging pathogens due to intensive cultivation. In recent decades, the increase in global rice production has mainly benefited irrigated high-yielding varieties due to research breakthroughs and technology transfer. Upland rice research has been extremely limited, with most findings remaining unpublished in the study area. Consequently, these successes have had a negligible effect on upland rice production.

The main objective of rice breeders is to strive for higher yields either in both irrigated and non-irrigated environments. This involves trying to improve adaptable varieties through structured selection from breeding diverse parents and identifying superior genotypes with desirable traits. Yield is a complex quantitative character that cannot be based on a single phenomenon. Other yield-contributing traits include plant height, leaf length, number of panicles per plant, number of grains per panicle, 1000-grain weight, days to flowering and days to maturity. The effective selection of superior genotypes for yield will associate yield with known attributing traits and consider these during the process (Neethu-Francis et al., 2018). The association among grain yields and yield component variables has been studied widely at the phenotypic level. Grain yield seems to have a significant correlation coefficient also with the number of filled grains per panicle, grain weight, panicle length, and grain count per panicle (Idris et al., 2012). Grain yield and number of grains per panicle, days to maturity, productive tillers, and days to flowering are clearly positively correlated (Sadeghi, 2011). Ullah et al. (2011) observed that grain yield and panicle length as well as the number of grains per panicle were positively and significantly related to each other. Hairmansis et al. (2010) discovered a relationship between grain yield and the number of filled grains per panicle, the number of spikelets per panicle, and spikelet fertility. Grain yield is considered as the most important characteristic, with high yield being the main goal of breeding in all crops. However, direct selection for yield is not very satisfactory as heritability is low. Several studies suggest using secondary traits, which include phenological, morphological, and physiological traits, as indirect selection criteria for higher yields. For instance, while correlation coefficients are important in determining what each secondary trait contributes to grain yield, they alone are not sufficient to determine whether the traits influence grain yield directly or indirectly (Nandan et al., 2010). The correlation coefficient can be divided into smaller components because one predictor variable has a direct effect on its response variable and because another predictor variable has a direct effect on the response variable through another predictor variable through path analysis, which breaks down the correlation coefficient into parts. Plant breeders use path analysis to find out which traits can be used as selection criteria to enhance crop yield (Sürek and Beser, 2003). Zou et al. (2005) have observed that spikelet fertility seems to be essential for grain yield under water deficit or drought-stress with a direct effect of P=0.60, whereas the number of spikelets per panicle makes the largest contribution to yield under well-watered conditions (P=0.41). In another study, Babu et al. (2012) found that the panicle length and the number of productive tillers on each plant had the most direct effect on yield through path coefficient analysis. Seyoum et al. (2012) found that the number of productive tillers, panicle weight, and spikelet fertility had positive and direct effects on grain yield in most of the studies analysed.

The aim of this study was to create several trait selection criteria for rice yield enhancement by using correlation and path coefficient analyses to find characteristics that have a direct effect on grain yield improvement in upland rice genotypes.

Material and Methods

The study was conducted in the 2019 and 2020 cropping seasons at two locations, the National Centre for Genetic Resources and Biotechnology (NACGRAB) in Ibadan, Oyo State and the Federal University of Agriculture Abeokuta (FUNAAB), Research and Experimental Farm in Ogun State using forty rice genotypes obtained from the Gene bank. Observations on culm length (cm), culm number, effective tillering, panicle length (cm), 1000-grain weight (g), plant height (cm), days to flowering, days to maturity, leaf length (cm), leaf width (mm), panicle number, grain length (mm), grain width (mm) and yield (kg plot $^{-1}$) were obtained and recorded.

The data obtained from the genotypes were subjected to correlation and path coefficient analyses. Estimates of genotypic and phenotypic correlations among yield and yield-related characters of the 40 genotypes of rice were conducted based on the environment using SAS version 9.4 (SAS Institute, 2000). The genotypic and phenotypic coefficients were partitioned to assess the direct and indirect effect of the yield-related trait on grain yield using path analysis in SAS software version 9.4.

Results and Discussion

The correlation coefficients for 14 quantitative traits among 40 rice genotypes across two locations and in two cropping seasons are presented in Table 1, differentiating between genotypic (upper diagonal) and phenotypic (lower diagonal) correlations. The genotypic correlation analysis reveals remarkable results. Culm length showed positive and significant correlations with panicle length, plant height, and leaf length. Similarly, culm number demonstrated positive and significant correlations with effective tillering and yield, while it exhibited a significant negative correlation with leaf width. Effective tillering displayed highly significant positive correlations with panicle number and yield, accompanied by significant negative correlations with 1000-grain weight and leaf width. Additionally, panicle length revealed highly significant positive correlations with plant height, leaf length, and grain length. Notably, 1000-grain weight exhibited highly significant negative correlations with panicle number and yield. These correlation analyses provide valuable insights into the relationships between these quantitative traits in rice genotypes under different environmental conditions and cropping seasons. The results highlight the significance of these traits for the expression of rice plant characteristics and ultimately for yield potential.

Plant height exhibited a remarkably strong and positive correlation with leaf length. Furthermore, days to flowering demonstrated a significant and positive correlation with days to maturity, while at the same time revealing a notable negative correlation with yield. Days to maturity exhibited a noteworthy negative correlation with yield. The panicle number displayed a significant and positive correlation with yield. The phenotypic correlation analysis, as depicted in Table 1, unveiled a robust and positive association between yield and panicle number. In addition, grain width demonstrated a positive and significant correlation with grain length, while grain length exhibited a negative and significant correlation with effective tillering, but simultaneously displayed a positive and significant relationship with 1000-grain weight. Leaf length was positively and significantly correlated with culm length, effective tillering, and panicle length. Conversely, leaf width exhibited a negative and significant correlation with culm number. Days to maturity displayed a highly significant and positive correlation with days to flowering. Additionally, plant height showed a highly significant positive correlation with culm length, while panicle length also exhibited a highly significant positive correlation with culm length. Lastly, effective tillering displayed a highly significant and positive correlation with culm number.

Table 1. Estimates of genotypic (upper diagonal) and phenotypic (lower diagonal) correlation coefficients of 14 quantitative characters in 40 rice genotypes at two locations in two cropping seasons.

Traits	CULL	CULN	EFFT	PAN	1000GRWT	PHT	DFLWR	DMATR	LFLN	LFWD	PANN	GRNL	GRNW	YLD
CULL		0.13	0.12	0.36*	-0.10	0.71**	-0.14	-0.11	0.59**	0.30	-0.02	-0.29	0.02	0.12
CULN	0.10		0.99**	-0.01	-0.29	-0.19	-0.11	-0.08	0.29	-0.56**	0.32*	-0.27	-0.13	0.34*
EFFT	0.11	0.89**		-0.02	-0.34*	-0.13	-0.05	-0.01	0.31	-0.52**	0.35*	-0.33*	-0.22	0.37*
PANL	0.23*	-0.09	-0.05		-0.14	0.63**	0.03	0.10	0.42*	0.00	-0.01	0.32*	-0.16	0.00
1000GRWT	-0.07	-0.16	-0.12	-0.08		0.09	-0.15	-0.13	-0.03	0.35	-0.38*	0.22	0.36	-0.36*
PHT	0.20*	-0.06	-0.06	0.10	-0.02		-0.09	-0.06	0.48*	0.37	-0.20	-0.13	-0.14	0.02
DFLWR	-0.12	-0.05	-0.04	-0.02	0.00	-0.01		1.00**	-0.22	-0.08	-0.28	-0.31	-0.1	-0.37*
DMATR	-0.09	-0.04	-0.01	-0.01	-0.02	0.00	0.88**		-0.10	-0.04	-0.32	-0.30	-0.16	-0.39*
LFLN	0.43**	0.21	0.24*	0.23*	-0.09	0.09	-0.16	-0.09		0.19	0.09	-0.13	-0.24	0.30
LFWD	0.10	-0.15*	-0.13	-0.01	0.07	0.05	-0.04	-0.08	0.13		-0.20	-0.11	-0.01	-0.01
PANN	-0.05	0.20	0.20	-0.06	-0.19	-0.04	-0.09	-0.11	0.05	-0.08		-0.13	0.06	0.87**
GRNL	-0.21	-0.13	-0.19*	0.14	0.17*	-0.04	-0.08	-0.08	-0.13	-0.04	-0.05		0.34	-0.24
GRNW	0.00	-0.01	-0.04	-0.09	0.20	-0.02	-0.07	-0.09	-0.08	-0.02	-0.01	0.18*		-0.09
YLD	0.07	0.21	0.21	0.03	-0.13*	0.01	-0.26*	-0.23*	0.14	-0.03	0.64**	-0.12	-0.04	

* and ** indicate significance at the 5% and 1% levels, respectively. CULL – culm length (cm), CULN – culm number, EFFT – effective tillering, PANL – panicle length (cm), 1000GRWT – 1000-grain weight (g), PHT – plant height (cm), FLWR – days to flowering, MATR – days to maturity, LFLN – leaf length (cm), LFWD – leaf width (mm), PANN – panicle number, GRNL – grain length (mm), GRNW – grain width (mm) and YLD – yield (kg/plot).

Table 2 shows the correlation coefficients for both genotypic and phenotypic traits for a dataset encompassing 40 different rice genotypes cultivated in Abeokuta during 2019. In the genotypic correlation analysis, culm length was found to have a significant positive correlation with panicle length, plant height, and leaf length.

Conversely, culm length displayed a noteworthy negative correlation with grain length. Additionally, culm number exhibited a positive and significant correlation with effective tillering, but a negative and significant correlation with 1000-grain weight. Notably, effective tillering displayed a highly significant negative correlation with 1000-grain weight. Furthermore, panicle length showed a strong positive correlation with plant height (0.46) and leaf length. It was evident that 1000-grain weight was negatively correlated with panicle number, while it showed a significant positive correlation with grain width and yield. Additionally, plant height exhibited a highly significant positive correlation with leaf length and leaf width. However, it was significantly negatively correlated with grain length. Furthermore, a significant and positive correlation was observed between days to flowering and days to maturity. Conversely, days to maturity displayed a negatively significant correlation with yield.

Table 2. Estimates of genotypic (upper diagonal) and phenotypic (lower diagonal) correlation coefficients among yield and yield-related characters in Abeokuta in 2019.

Traits	CULL	CULN	EFFT	PANL	1000GRWT	PHT	DFLWR	DMATR	LFLN	LFWD	PANN	GRNL	GRNW	YLD
CULL		0.04	0.06	0.33*	-0.03	0.85**	-0.22	-0.27	0.60**	0.40*	-0.17	-0.37*	-0.20	0.09
CULN	0.03		0.99**	-0.06	-0.37*	0.00	-0.01	-0.05	0.20	-0.28	0.18	-0.19	-0.24	0.30
EFFT	0.05	0.98**		-0.02	-0.36*	0.01	0.00	-0.03	0.26	-0.23	0.16	-0.24	-0.29	0.29
PANL	0.32*	-0.06	-0.02		-0.03	0.46**	-0.12	-0.13	0.58**	0.14	-0.12	0.07	-0.21	-0.09
GRWT	-0.04	-0.39*	-0.39*	-0.03		-0.04	-0.13	-0.13	0.05	0.18	-0.32*	0.23	0.34*	-0.26
PHT	0.84**	0.00	0.01	0.44**	-0.04		-0.25	-0.24	0.66**	0.45**	-0.14	-0.33*	-0.28	0.10
FLWR	-0.22	0.01	0.02	-0.11	-0.12	-0.25		1.00**	-0.26	-0.06	-0.1	-0.16	-0.09	-0.30
MATR	-0.25	-0.04	-0.02	-0.11	-0.11	-0.23	0.95**		-0.26	-0.05	-0.17	-0.18	-0.08	-0.39*
LFLN	0.56**	0.18	0.24	0.52**	0.03	0.62**	-0.25	-0.25		0.41**	0.00	-0.12	-0.16	0.24
LFWD	0.38*	-0.26	-0.2	0.13	0.17	0.43	-0.06	-0.05	0.36*		-0.29	-0.13	-0.13	-0.23
PANN	-0.18	0.16	0.14	-0.12	-0.34	-0.14	-0.09	-0.15	0.00	-0.27		-0.05	-0.12	0.75**
GRNL	-0.37*	-0.21	-0.26	0.05	0.20	-0.32*	-0.14	-0.15	-0.12	-0.11	-0.07		0.60**	-0.14
GRNW	-0.18	-0.21	-0.26	-0.18	0.30	-0.25	-0.07	-0.08	-0.16	-0.12	-0.11	0.50**		0.01
YLD	0.07	0.28	0.27	-0.10	-0.28	0.10	-0.28	-0.34*	0.22	-0.20	0.72**	-0.15	-0.01	

* and ** indicate significance at the 5% and 1% levels, respectively. CULL – culm length (cm), CULN – culm number, EFFT – effective tillering, PANL – panicle length (cm), 1000GRWT – 1000-grain weight (g), PHT – plant height (cm), FLWR – days to flowering, MATR – days to maturity, LFLN – leaf length (cm), LFWD – leaf width (mm), PANN – panicle number, GRNL – grain length (mm), GRNW – grain width (mm) and YLD – yield (kg/plot).

In the context of the phenotypic correlation analysis (as shown in Table 2), several significant associations were observed. Specifically, yield exhibited a notable negative and significant correlation with days to maturity, while it displayed a positive and significant correlation with panicle number due to the genetic nature of the materials under evaluation and some interactions with the environment. Furthermore, grain width displayed a significant and positive correlation with grain length. In contrast, grain length exhibited a negative and significant correlation with culm length and plant height. Additionally, leaf width showed positive and significant correlations with culm length and leaf length. Leaf length was positively and significantly correlated with culm length, panicle length, and plant height. In 2019, there was a highly significant positive correlation between days to maturity and days to flowering in Abeokuta (as shown in Table 2). Plant height exhibited highly significant positive correlations with culm length and panicle length. Additionally, 1000-grain weight demonstrated highly significant negative correlations with culm number and effective tillering (-0.39 each). Effective tillering, on the other hand, exhibited a significant positive correlation with culm number. Furthermore, the correlation coefficients for 14 quantitative traits among 40 rice genotypes in Abeokuta in 2020 (as shown in Table 3) highlighted significant associations. Notably, culm length displayed positive and significant associations with panicle length, plant height, and leaf length, while negatively and significantly correlating with 1000-grain weight. Culm number exhibited positive and significant correlations with effective tillering and leaf length but was negatively and significantly correlated with panicle length.

Table 3. Estimates of genotypic (upper diagonal) and phenotypic (lower diagonal) correlation coefficients among yield and yield-related characters in Abeokuta in 2020.

Traits	CULL	CULN	EFFT	PANL	1000GRWT	PHT	FLWR	MATR	LFLN	LFWD	PANN	GRNL	GRNW	YLD
CULL		0.12	0.19	0.40*	-0.33*	0.75**	-0.06	-0.03	0.68**	NA	-0.01	-0.29	0.19	-0.06
CULN	0.10		0.97**	-0.35*	-0.20	-0.04	-0.04	0.06	0.33*	NA	0.37*	-0.09	0.26	0.15
EFFT	0.17	0.94**		-0.37*	-0.31	0.02	0.01	0.12	0.35*	NA	0.33*	-0.25	0.12	0.17
PANL	0.30	-0.29	-0.29		-0.60**	0.51**	-0.1	-0.04	0.21	NA	0.33*	0.25	0.39*	0.31
GRWT	-0.23	-0.15	-0.12	-0.27		-0.24	0,00	-0.01	-0.30	NA	-0.42**	0.28	0.18	-0.39*
PHT	0.68**	-0.04	0.01	0.38*	-0.12		-0.17	-0.1	0.63**	NA	-0.04	-0.19	-0.31*	0.09
FLWR	-0.06	-0.03	0.02	-0.05	0.03	-0.14		1.00**	0.27	NA	-0.20	-0.16	-0.18	-0.29
MATR	-0.03	0.07	0.12	0.00	0.01	-0.08	0.95**		0.29	NA	-0.22	-0.21	-0.25	-0.22
LFLN	0.66**	0.31*	0.32*	0.15	-0.18	0.54**	0.23	0.25		NA	0.02	-0.21	-0.19	-0.10
LFWD	-0.04	-0.06	-0.04	-0.41**	-0.04	-0.02	-0.01	-0.09	-0.06		NA	NA	NA	NA
PANN	-0.02	0.28	0.25	0.15	-0.29	-0.06	-0.16	-0.17	0.02	0.03		-0.07	-0.13	0.81**
GRNL	-0.27	-0.13	-0.24	0.18	0.15	-0.20	-0.13	-0.12	-0.17	0.05	-0.04		0.04	-0.17
GRNW	0.12	0.14	0.07	0.07	0.13	-0.18	-0.11	-0.10	-0.07	0.11	-0.03	0.01		-0.23
YLD	-0.06	0.15	0.15	0.23	-0.28	0.08	-0.27	-0.20	-0.10	0.02	0.75**	-0.14	-0.10	

* and ** indicate significance at the 5% and 1% levels, respectively. CULN – culm number, EFFT – effective tillering, PANL – panicle length (cm), 1000GRWT – 1000-grain weight (g), PHT – plant height (cm), FLWR – days to flowering, MATR – days to maturity, LFLN – leaf length (cm), LFWD – leaf width (mm), PANN – panicle number, GRNL – grain length (mm), GRNW – grain width (mm) and YLD – yield (kg/plot).

In the correlation analysis, several associations were observed among different traits in rice plants. Panicle length showed a significant negative correlation with

1000-grain weight, but a positive correlation with plant height. Conversely, 1000-grain weight had a significant negative correlation with panicle number. Plant height had a significant positive correlation with leaf length, but a significant negative correlation with grain width. Days to flowering had a significant positive correlation with days to maturity, indicating a connection between these developmental stages. Panicle number showed a significant positive correlation with yield, highlighting its importance for grain production. Yield was positively associated with panicle number, indicating its significance as a yield determinant. Leaf width had a significant negative correlation with panicle length. Leaf length exhibited highly significant positive correlations with culm length, culm number, effective tillering, and plant height, showing its multifaceted relationship with various traits. Plant height had positive and significant correlations with culm length and panicle length, emphasising its influence on these traits. Effective tillering had a significant positive correlation with culm number, indicating its role in promoting culm development. In genotypic correlation analysis among 40 rice genotypes in Ibadan in 2019 (as detailed in Table 4), culm length was positively associated with panicle length, plant height, leaf length, and leaf width, but negatively associated with 1000-grain weight. Culm number had a positive correlation with effective tillering, but negative correlations with 1000-grain weight, leaf width, and grain width.

The correlations clearly show that effective tillering exhibited a favourable correlation with leaf length, while simultaneously displaying highly significant negative correlations with 1000-grain weight, grain length, and grain width. Moreover, panicle length emerges as a key factor, showing highly significant positive correlations with plant height and leaf length. In contrast, 1000-grain weight unveiled a complex relationship, showing highly significant negative correlation with panicle number and a positive correlation with grain width. The stature of the rice plants cannot be overlooked, as plant height exhibited highly significant positive correlations with both leaf length and leaf width. Days to flowering and days to maturity exhibited significant correlations, with the former displaying a positive correlation with the latter and a negative correlation with yield. Days to maturity, on the other hand, presented a significant negative correlation with yield. Notably, panicle number emerged as a vital factor, establishing a significantly positive correlation with yield.

The exploration of phenotypic correlations, as illustrated in Table 4, illuminates the relationship between yield and other traits. Yield, the ultimate measure of success, showed a significant positive association with panicle number but also showed a negative correlation with days to flowering. Leaf width stood out with its noteworthy relationships, displaying significantly positive correlations with culm length and plant height, while concurrently manifesting a significant negative correlation with culm number. Grain width showed a significant negative correlation with effective tillering. Panicle number, a key determinant of yield, displayed a highly significant negative correlation with 1000-grain weight and leaf width. The towering stature of the rice plants, which is expressed by plant height, revealed significant positive correlations with both culm length and panicle length. Further investigation of 1000-grain weight unveiled its intricate associations, with highly significant negative correlations with culm number and effective tillering. Additionally, panicle length exhibited a significant positive correlation with culm length, emphasising the synergy between these traits. The importance of effective tillering was underscored by its significant positive correlation with culm number, highlighting its role in determining yield potential.

Table 4. Estimates of genotypic (upper diagonal) and phenotypic (lower diagonal) correlation coefficients among yield and yield-related characters in Ibadan in 2019.

Traits	CULL	CULN	EFFT	PANL	GRWT	PHT	FLWR	MATR	LFLN	LFWD	PANN	GRNL	GRNW	YLD
CULL		0.07	0.07	0.42**	-0.04	0.85**	-0.25	-0.23	0.46**	0.36*	-0.12	-0.33*	0.07	0.13
CULN	0.06		0.99**	0.05	-0.33*	0.05	-0.04	-0.03	0.37*	-0.33*	0.17	-0.31	-0.34*	0.24
EFFT	0.05	0.98**		0.06	-0.31*	0.06	0.03	0.04	0.38*	-0.30	0.11	-0.32*	-0.41**	0.20
PANL	0.39*	0.03	0.04		0.00	0.45**	-0.20	-0.23	0.51**	0.19	-0.18	0.11	-0.23	-0.08
GRWT	-0.06	-0.35*	-0.33*	-0.01		0.00	-0.13	-0.14	-0.03	0.28	-0.37*	0.17	0.46**	-0.21
PHT	0.84*	0.06	0.06	0.42**	-0.01		-0.26	-0.25	0.44*	0.40*	-0.16	-0.28	-0.15	0.13
FLWR	-0.24	-0.02	0.04	-0.19	-0.11	-0.25		1.00**	-0.34*	-0.12	-0.07	-0.07	-0.03	-0.35*
MATR	-0.22	-0.01	0.05	-0.22	-0.12	-0.24	0.99**		-0.31	-0.12	-0.07	-0.08	0.00	-0.34*
LFLN	0.45**	0.35*	0.36*	0.46**	-0.04	0.43**	-0.33*	-0.30		0.31*	0.01	-0.07	-0.27	0.24
LFWD	0.36*	-0.31*	-0.29	0.18	0.28	0.38*	-0.12	-0.12	0.31		-0.35*	-0.18	-0.26	-0.23
PANN	-0.13	0.15	0.09	-0.18	-0.38*	-0.15	-0.06	-0.05	0.00	-0.32*		-0.16	0.08	0.85**
GRNL	-0.31	-0.28	-0.28	0.08	0.12	-0.23	-0.04	-0.05	-0.1	-0.15	-0.16		0.34*	-0.29
GRNW	0.00	-0.30	-0.34*	-0.21	0.27	-0.09	0.01	0.03	-0.22	-0.16	0.02	0.26		-0.14
YLD	0.10	0.21	0.17	-0.09	-0.23	0.13	-0.33*	-0.31	0.22	-0.22	0.80**	-0.27	-0.13	

* and ** indicate significance at the 5% and 1% levels, respectively. CULL – culm length (cm), CULN – culm number, EFFT – effective tillering, PANL – panicle length (cm), 1000GRWT – 1000-grain weight (g), PHT – plant height (cm), FLWR – days to flowering, MATR – days to maturity, LFLN – leaf length (cm), LFWD – leaf width (mm), PANN – panicle number, GRNL – grain length (mm) , GRNW – grain width (mm) and YLD – yield (kg/plot).

The results pertaining to the genotypic (upper diagonal) and phenotypic (lower diagonal) correlation coefficients of 14 quantitative characteristics of rice in the 2020 Ibadan study are meticulously laid out in Table 5. The genotypic analysis clearly shows that culm length showed a significantly positive association with panicle length and leaf length. In a parallel vein, culm number established a noteworthy positive correlation with effective tillering and yield, while concurrently displaying a substantial negative correlation with leaf width. The parameter of effective tillering emerged as a pivotal factor, unveiling highly significant negative correlations with 1000-grain weight and leaf width, along with a positive correlation with panicle number and yield. Meanwhile, panicle length proved to be a key determinant and showed highly significant positive correlations with leaf length, leaf width, and grain length. The intricate web of correlations extends further, as 1000-grain weight established a significant negative correlation with days to flowering, days to maturity, panicle number, and yield. In contrast, 1000-grain weight demonstrated significant positive correlations with leaf length, leaf width, grain length, and grain width. It was observed that days to flowering exhibited a significant positive correlation with days to maturity, while simultaneously displaying a negative correlation with leaf width, grain width, and yield. Days to maturity, on the other hand, exhibited significant negative correlations with grain length, grain width, and yield. Leaf width, an often-overlooked trait, showed a significant negative correlation with panicle number and a substantial positive correlation with grain length. Panicle number, a prominent player in determining yield, established a significant positive correlation with yield, while simultaneously manifesting a substantial negative correlation with grain length. When analysing phenotypic direct and indirect effects, Figure 1 illuminates that four traits are statistically significant. Among them, grain weight, flowering, and maturity exhibited significant negative correlations with yield at the 5% level of significance, underscoring their influence on yield dynamics. In stark contrast, panicle number proved to be an outstanding influencing factor with a significantly positive correlation with yield at the remarkable 1% level of significance. The path analysis, as delineated in Figure 2, provides a deeper understanding of the genotypic direct and indirect determinants of yield in the 40 rice genotypes. Within this intricate interplay, four traits emerged as statistically significant. Notably, grain weight, flowering, and maturity were found to have significant negative correlations with yield at the 5% level of significance, casting a shadow on yield prospects. In a parallel vein, culm number, effective tillering, and panicle number were found to be the driving forces behind yield, as they showed significantly positive correlations with yield, distinguished at both the 5% and 1% levels of significance.

Such interrelationships can provide valuable insights into indirect selection strategies aimed at enhancing overall yield, as shown by Htwe et al. (2019). Notably, a robust and consistently positive genotypic and phenotypic correlation surfaced between yield per plant and panicle number per plant across all environments. This finding underscores the significance of panicle number as a major factor in increasing grain yield. It further highlights that direct selection for panicle number can be an effective strategy to increase rice yields. In the realm of trait evaluation, the reliability of inter-character association estimates depends on the presence of both significant genotypic and phenotypic correlations, as explained by Ogunbayo et al. (2014). The substantial and consistently positive genotypic and phenotypic correlations identified in various environments, including those between plant height and culm length, effective tillering and culm number, days to flowering and days to maturity, leaf length and culm length, and leaf length and panicle length, underscore the central role that these traits play in relation to grain yield. This robust correlation framework is convincing evidence that these traits are of paramount importance in the context of grain yield enhancement.

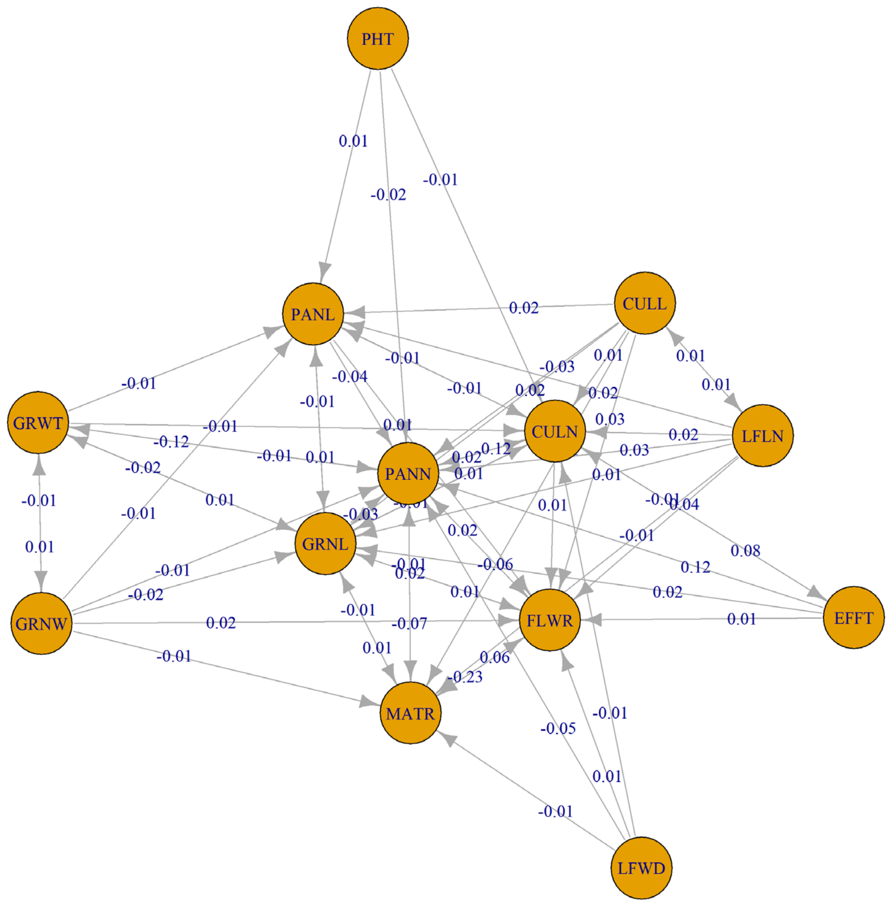

Figure 1. Phenotypic direct and indirect effects of characters on the yield of 40 rice genotypes for path analysis.

Significant at * $P < 0.05$; ** $P < 0.01$, Residual = 0.72, CULL – culm length (cm), CULN – culm number, EFFT – effective tillering, PANL – panicle length (cm), 1000GRWT – 1000-grain weight (g), PHT – plant height (cm), FLWR – days to flowering, MATR – days to maturity, LFLN – leaf length (cm), LFWD – leaf width (mm), PANN – panicle number, GRNL – grain length (mm), GRNW – grain width (mm).

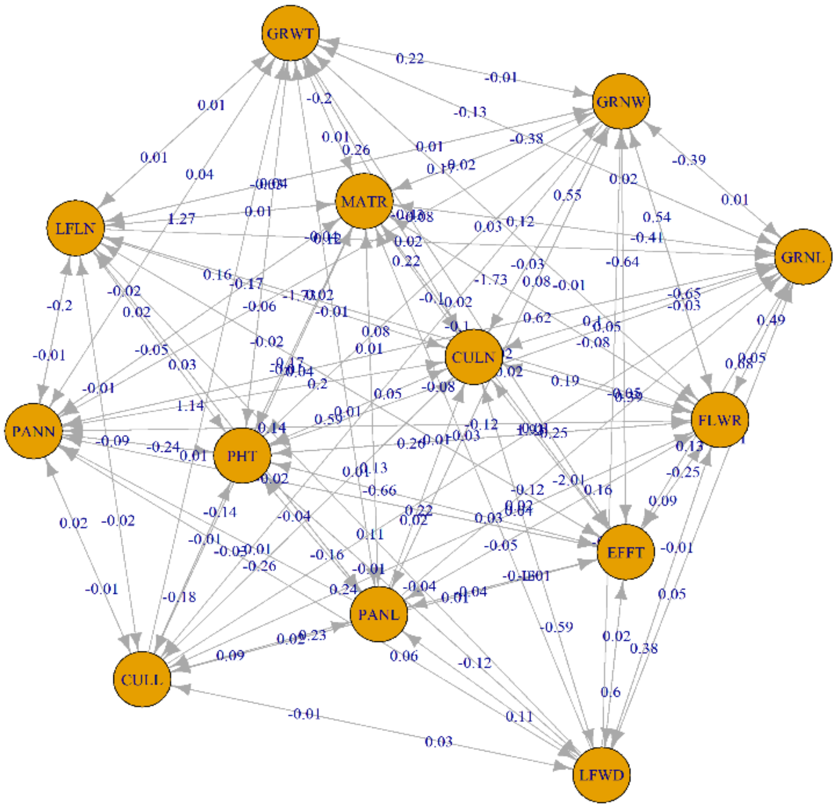

Figure 2. Genotypic direct and indirect effects of characters on the yield of 40 rice genotypes for path analysis.

Significant at * P < 0.05; ** P < 0.01, Residual = 0.44, CULL – culm length (cm), CULN – culm number, EFFT – effective tillering, PANL – panicle length (cm), 1000GRWT – 1000-grain weight (g), PHT – plant height (cm), FLWR – days to flowering, MATR – days to maturity, LFLN – leaf length (cm), LFWD – leaf width (mm), PANN – panicle number, GRNL – grain length (mm), GRNW – grain width (mm).

This also underscores the effectiveness of focusing selection efforts on these specific traits to ensure improved grain yield in rice. This observation aligns with the findings of Htwe et al. (2019), who also documented substantial positive genotypic and phenotypic correlations between yield per plant and key indicators such as the effective tillering, panicle/straw ratio, harvest index, filled grain percentage, and the number of spikelets per panicle. These results are consistent with the research of Ogunbayo et al. (2014), who revealed a significant positive association between grain yield and the number of panicles per plant, and Ramakrishman et al. (2006), who reported a similar correlation for the number of spikelets per panicle. Conversely, yield per plant exhibited a significant negative correlation with 1000-grain weight, days to flowering, and days to maturity. Thus, enhancing grain yield per plant could be achieved by selecting genotypes with early flowering and maturation. These findings are consistent with those of Htwe et al. (2019), who also identified negative correlations between grain yield and days to flowering, panicle length, and 1000-grain weight. Consequently, based on the insights derived from correlation studies, it can be inferred that genotype should possess a higher number of panicles per plant, a greater panicle length per plant, an increased culm number per plant, a longer culm length per plant, a higher number of effective tillers, early flowering, and maturation, and a longer leaf length in order to increase the grain yield of rice.

Table 5. Estimates of genotypic (upper diagonal) and phenotypic (lower diagonal) correlation coefficients among yield and yield-related characters in Ibadan in 2020.

Traits	CULL	CULN	EFFT	PANL	1000GRWT	PHT	FLWR	MATR	LFLN	LFWD	PANN	GRNL	GRNW	YLD
CULL		0.17	0.04	0.34*	0.17	NA	0.11	0.2	0.54**	-0.06	0.04	-0.1	0.06	0.07
CULN	0.13		0.94**	-0.1	-0.19	NA	-0.13	-0.24	-0.1	-0.60**	0.31	0	0.11	0.33*
EFFT	0.05	0.87**		0.02	-0.43**	NA	-0.19	-0.2	0.05	-0.64**	0.43**	-0.19	0.01	0.39*
PANL	0.22	-0.19	-0.08		0.01	NA	0.12	0.21	0.85**	0.45**	0.23	0.62**	-0.22	0.17
GRWT	0.12	-0.12	-0.23	-0.07		NA	-0.40*	-0.52**	0.39**	0.47**	-0.43**	0.96**	0.38*	-0.34*
PHT	-0.02	-0.17	-0.27	0.03	-0.02		NA	NA	NA	NA	NA	NA	NA	NA
FLWR	0.08	-0.13	-0.17	0.17	0.06	0.03		0.98**	-0.25	-0.34*	0.1	0.3	-0.77**	-0.49**
MATR	0.13	-0.18	-0.16	0.15	-0.05	0.06	0.80**		-0.24	-0.23	-0.13	-0.87**	-0.87**	-0.48**
LFLN	0.39*	-0.05	0.06	0.29	0.09	-0.3	-0.16	-0.09		0.29	0.31	-0.11	0.04	0.23
LFWD	-0.01	-0.48**	-0.51**	0.19	0.33*	0.32*	-0.18	-0.1	0.18		-0.57**	0.56**	0.28	-0.04
PANN	0.02	0.24	0.34*	0.09	-0.21	-0.16	0.08	-0.06	0.22	-0.39*		-0.48**	0.03	0.51**
GRNL	-0.13	0.03	-0.11	0.16	0.35*	0.15	0.06	-0.2	-0.13	0.17	-0.23		0.51**	-0.35*
GRNW	0.04	0.12	0.03	-0.11	0.32*	0	-0.38*	-0.52**	0	0.07	0.06	0.31		-0.02
YLD	0.08	0.21	0.29	0.16	-0.17	-0.17	-0.24	-0.26	0.17	-0.08	0.53**	-0.18	-0.06	

* and ** indicate significance at the 5% and 1% levels, respectively. CULL – culm length (cm), CULN – culm number, EFFT – effective tillering, PANL – panicle length (cm), 1000GRWT – 1000-grain weight (g), PHT – plant height (cm), FLWR – days to flowering, MATR – days to maturity, LFLN – leaf length (cm), LFWD – leaf width (mm), PANN – panicle number, GRNL – grain length (mm), GRNW – grain width (mm) and YLD – yield (kg/plot).

The estimation of genotypic and phenotypic correlation coefficients is very useful in plant breeding, facilitating selection based on phenotypic performance. In the context of Abeokuta in 2019, the computed genotypic and phenotypic correlation coefficients for the number of days to maturity and yield, as well as for panicle number and yield were notably significant. These results imply that the selection of early maturing genotypes and those with a higher number of panicles can effectively contribute to an increased yield. Conversely, in Abeokuta 2020, the negative correlation observed between grain width and yield suggests an inverse relationship. To enhance yield, grains with a reduced width would therefore have to be selected.

The noteworthy negative correlation between the number of days to flowering and maturity and yield observed in Ibadan during 2019 implies that enhancing the genotypes requires the selection of early flowering and early maturing plants. Conversely, the significant correlations between culm number, effective tillering, and panicle number with yield in Ibadan in 2020 suggest that improving these traits will ultimately lead to increased yield. However, the negative correlations observed between grain width, the number of days to flowering and maturity with yield suggest that reducing these traits would result in a simultaneous increase in yield. It is worth noting that the number of genetic components influencing the direction of association between traits tends to vary with the environment, as highlighted by Obilana and Fakorede (1986) and Bänziger et al. (2006). As Shukla et al. (2004) point out, a comprehensive understanding of the genetic parameters in different environments is therefore essential to enable effective selection and progress in breeding programmes.

Path analysis, a valuable tool, allows the separation of direct effects and corresponding indirect effects through other attributes, providing a more comprehensive explanation of cause and effect (Sadeghi, 2011). In the context of path analysis, grain yield per plant serves as the dependent variable. The study assessed the direct and indirect phenotypic effects of various characters. Panicle number exhibited the most substantial direct phenotypic effect on grain yield. Furthermore, panicle number displayed a highly significant positive correlation with grain yield per plant. A separate study conducted by Htwe et al. (2019) also reported that spikelets per panicle, effective tillers per plant, and filled grain percentage had direct effects on yield, with these characters demonstrating positive and highly significant correlations with yield per plant.

The direct and indirect contributions of the traits to the genotypic correlation revealed a substantial and positive direct effect of panicle number, culm number, and effective tillering on the rice grain yield of the 40 genotypes. These traits should be adequately considered when selecting for yield among the cultivars. Neethu-Francis et al. (2018) also reported a significantly positive direct effect of the number of panicles per plant, the number of grains per panicle, and 1000-grain weight on the yield of rice cultivars.

The negative direct effect of these traits on yield has also been reported by Neethu-Francis et al. (2018) and Devendra et al. (2016), aligning with the findings of this study. Other traits showed a negative indirect effect on grain yield through grain weight, days to flowering, and days to maturity, and a moderately positive indirect influence on grain yield through culm number and effective tillering. Htwe et al. (2019) also reported that the number of spikelets per panicle had a positive direct effect on yield per plant of Myanmar local rice. Additionally, panicle/straw weight ratio and panicle length were found to have a high indirect effect via effective tillering on the yield of Myanmar local rice (Htwe et al., 2019).

The fact that five traits (effective tillering, panicle length, days to maturity, panicle number, and grain width) exhibited a positive direct effect on grain yield at the genotypic level suggests that any of these traits can be used in a rice improvement programme under the conditions of the study. However, the positive indirect effect of culm number, grain weight, plant height, days to flowering, leaf length, leaf width, and grain length can offset the negative direct effect on grain yield. Therefore, it is advisable to prioritise all the traits studied in rice improvement. Akinyele and Osekita (2006) noted that high indirect effects of traits can counterbalance low direct effects of traits on crop yield.

The residual effect of 0.72 at the phenotypic level indicates that the selected characters contributed to 28% of the variability. At the genotypic level, the residual effect was 0.44, suggesting that the characters studied in this research contributed to 56% of the variability. According to Htwe et al. (2019), the residual effect typically determines how effectively the causal factors account for the variability of the dependent factors, such as the standard evaluation score.

Conclusion

Panicle number directly impacts grain yield, with more panicles leading to higher yields. Other factors such as panicle length, culm number, effective tillering, and days to maturity also influence grain yield. In all environments, positive correlations were found between yield per plant and panicle number per plant, establishing the importance of panicle number in increasing grain yield. To improve rice grain yield, varieties should possess traits such as increased panicle and culm numbers, longer panicles and culms, more effective tillering, early flowering and maturation, and greater leaf length per plant. These traits significantly correlate with yield. In Abeokuta in 2019 and 2020, traits such as panicle number, panicle length, effective tillering, culm length, plant height, leaf length, days to flowering, days to maturity, grain length, and grain width were found to have correlated with grain yield.

Culm length, culm number, effective tillering, plant height, days to flowering, panicle number and days to maturity showed correlated responses to grain yield in Ibadan in 2019. In 2020, traits such as culm number, effective tillering, grain length, 1000-grain weight, panicle number, days to flowering and days to maturity were correlated with grain yield in Ibadan. Developing improved rice genotypes that are adaptable to diverse environmental conditions is advisable, as the traits in the study area were mainly influenced by genetics and may be subjective in other locations under similar environmental conditions. It is therefore recommended that environmental conditions be considered as a factor in the quest to genetically improve rice and ensure sustainable production in the agro-ecology of Nigeria.

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ANALIZA GENOTIPSKIH I FENOTIPSKIH KORELACIJA I KOEFICIJENATA PUTA KOD 40 GENOTIPOVA PLANINSKOG PIRINČA (*ORYZA SATIVA* L.) U KIŠNIM OBLASTIMA U REGIONIMA DRŽAVA OJO I OGUN U NIGERIJI

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R e z i m e

Održiva proizvodnja pirinča u planinskim staništima zavisi od postizanja većih prinosa. Ova studija koristi korelacionu analizu i analizu koeficijenata puta kako bi se identifikovali kriterijumi ključnih osobina za unapređenje prinosa pirinča kod planinskih genotipova. Studija obuhvata dva vegetaciona perioda sa 40 genotipova. Genotipska korelaciona analiza pokazuje jaku pozitivnu korelaciju efikasnog bokorenja sa brojem metlica i prinosom. Naročito pokazuje značajne negativne korelacije sa masom 1000 zrna i širinom lista na različitim lokacijama i u različitim sezonama. Pored toga, fenotipske procene ističu značajnu pozitivnu korelaciju između prinosa i broja metlica. Dalje, analiza puta pokazuje da broj metlica održava značajno pozitivnu povezanost sa prinosom na nivou značajnosti od 5%. Osim toga, analiza direktnih i indirektnih genotipskih uticaja ističe značaj broja stabala, efikasnog bokorenja i broja metlica, od kojih svi pokazuju izuzetne i pozitivne korelacije sa prinosom, postižući statističku značajnost na nivou i od 5% i 1%. Da bi se poboljšao prinos zrna pirinča, genotip mora imati povećan broj ključnih osobina po biljci, uključujući povećan broj metlica, povećanu dužinu metlice, veći broj stabala, veću dužinu stabla, povećan broj efikasnih bokora, rani početak cvetanja, ubrzano sazrevanje i povećanu dužinu lista. Ove karakteristike su ključne determinante koje značajno doprinose ukupnom prinosu zrna u gajenju pirinča i od suštinskog su značaja za održivo unapređenje pirinča u ovim agroekološkim uslovima.

Ključne reči: genetička raznovrsnost, unapređenje pirinča, prinos, karakteristike povezane sa prinosom, interakcije genotipa sa okruženjem.

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