Variability and genetic parameters for nutritional quality traits of macaroni wheat (*Triticum durum* L.) genotypes

**Abstract:**

The present investigation was carried out to study genetic variability and genetic parameters for nutritional quality traits in sixteen macaroni wheat genotypes along with the five checks *i.e.* Panchavati, Godavari, MACS-3949, NIDW-1149, AKDW-2997-16. Nine quality characters were studied to estimate variability and genetic parameters. Statistical analysis revealed that significant differences for all the characters studied, indicating presence of considerable amount of variations among genotypes. Phenotypic coefficient of variation (PCV) was found to be higher than the genotypic coefficient of variation (GCV) for all the characters. This confirms a wider genetic variability observed among the sixteen durum wheat. Heritability in broad sense ranged from 82.12% to 99.96 %. Highest estimate of heritability was recorded for calcium content (99.96%) followed by sodium content (99.81%), Estimates of genetic advance ranged from 0.19 to 7.45. The highest estimate for genetic advance were recorded for Mg content (7.45) followed by Ca content (5.03). The significant positive correlation was found between protein content (%) with fiber content (%) and all minerals except Na content (mg/100 g) at both genotypic and phenotypic level. The performance of macaroni wheat genotypes for nutritional traits *viz.,* NIDW-1582, NIDW-1556, NIDW-1555 have high protein content, NIDW-1582, NIDW-1556 for Iron content, NIDW-1582, NIDW-1556, NIDW-1555 for zinc content, NIDW-1569 calcium content and NIDW-1556 for magnesium content could be utilized in further breeding programme to develop a new biofortified varieties in macaroni wheat.

**Key Words:** Macaroni Wheat, Variability, Nutritional traits, Correlation

**1. Introduction:**

“Agriculture plays a crucial role in improving food availability and achieving global food security. Despite this, while there is widespread acknowledgment of the increasing global demand for food in the coming decades. However the increasing concern over nutritionally smart crops challenges its acceptability as a staple source of nutritious diet and also enhancing food provision by increasing agricultural productivity. The predicted increase in global food demand necessitates the expansion of yield of major global food crops like wheat, rice, and maize with nutritious supplement, Biofortification has evolved and accepted as a strategy to address this issue of food and nutritional security. Climate change is continuously posing as a challenge with the evolution of new races of pathogen and pests in major crops” (Bhagat *et al.,* 2024).

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“Wheat is the foremost and strategic cereal crop of the world. Wheat is the most important and major staple food of more than thirty-five percent of worlds’ population. Globally, it is the most oldest and edible grain cereals. Wheat belongs to the tribe Triticeae, sub tribe Triticineae in the grass family Poaceae (Gramineae)” (Briggle and Reitz, 1963).

“Macaroni wheat (*Triticum durum* L.) is tetraploid wheat, having 4 sets of chromosomes for a total of 28, unlike hard red winter and hard red spring wheats, which are hexaploid (6 sets of chromosomes) for a total of 42 chromosomes each. Macaroni wheat originated through intergeneric hybridization and polyploidization involving two diploid (having 2 sets of chromosomes) grass species. Macaroni wheat accounts for about 3-5 % of total area sown under wheat and 6-8% of the total wheat production” (FAOSTAT, 2022-23). It contains stronger gluten, yellow colour grains, maintain good texture, resistant surface disintegration, retain structure and longer durability makes it more suitable for pasta making (Taneva et al., 2019).

It provides about one-half of human food calories and a large part of their nutrient requirements. Wheat contains carbohydrate (78.1%), protein (14.7%), fat (2.1%), minerals (2.1%) and considerable proportions of vitamins (thiamine, niacin and vitamin-B) and minerals (zinc, iron). It is also a good source of trace minerals like selenium and magnesium (Kumar *et al*. 2011).

The selection of high‐yielding macaroni wheat germplasm should not rely solely on grain yield as a criterion. Nutritional traits such as, crude protein, crude fiber, selenium, magnesium and nutritional quality play a crucial role in identifying and improving high‐performing varieties, particularly in environments characterized by climatic variability and abiotic constraints. These traits, often more heritable and stable than yield itself, enable more effective indirect selection, helping to overcome challenges associated with the polygenic complexity of grain yield and genotype × environment interactions.

“Iron and zinc concentrations are particularly low in regularly consumed cereal-based diets” (Cakmak 2008) which manifest as hidden hunger with serious consequences for health. “Genetic biofortification entails breeding strategies to identify and take advantage of genetic diversity for minerals, as well as novel methods involving gene discovery and breeding using marker assistance” (Grusak 2002).

“Biofortification overcome the problem of hidden hunger by improving the micronutrient content of the crops themselves by increasing mineral levels and bioavailability in the edible parts. Improving crop varieties by conventional breeding has the advantage that once the initial research and development is completed, the benefits from these nutritionally-enhanced crops will be sustainable with little further investment” (Gomez-Galera *et. al.* 2010). The biofortification breeding program uses the existing genetic diversity from various species and landraces to generate nutrient-enriched wheat germplasm with competitive yield potential and stress tolerance in order to satiate the hidden hunger of the expanding population.

The knowledge of variability also helps to develop strategies to incorporate useful diversity in breeding programs. This study aims to characterize the variability of agro‐morphological and quality traits within a collection of macaroni wheat. In views of these facts, twenty one wheat genotypes were evaluated in this study to determine the magnitude of variability among the germplasm for quality traits and to identify nutritionally desirable genotypes for exploitation in a breeding programme.

**2. Material and Methods:**

The present investigation nutritional diversity in macaroni wheat genotypes (*Triticum macaroni* *L*.) was carried out at Soil Science and Biochemistry laboratory, Post Graduate Institute, Mahatma Phule Krishi Vidyapeeth, Rahuri (Maharashtra) during year 2022-23. In which experiment conducted in pot culture at Biochemistry laboratory. The plant material for the study comprised of twenty-one wheat genotypes*, i.e.* Panchavati (Check) best suitable for macroni making, Godavari (Check) Protein content-12%, MACS-3949 (Check) better nutritional quality Zn-40.6 ppm, Fe-38.6 ppm, Protein-12.9%, good pasta making quality, NIDW-1149 (Check) Zn-37.6 ppm, Fe-38.4 ppm, Protein-11.37%,good for making pasta AKDW-2997-16 (Check) medium duration variety, NIDW-1569, NIDW-1572, NIDW-1573, NIDW-1574, NIDW-1576, NIDW-1578, NIDW-1579, NIDW-1582, NIDW-1555, NIDW-1561, NIDW-1542, NIDW-1556, NIDW-1557, NIDW-1520, NIDW-1534 and NIDW-1499 which were collected from Agriculture Research Station Niphad, District Nashik, Maharashtra and used for research work. Observations recorded for Crude Protein, Crude Fiber, Crude fat, Minerals Iron, zinc and other minerals.

Table 1:List of macaroni wheat genotypes used for analysis.

|  |  |  |
| --- | --- | --- |
| **Sr. No** | **Name of Genotype** | **Pedigree** |
| 1 | Panchavati (C) | DOM50 |
| 2 | Godavari (C) | Boomer33/PLATA8 |
| 3 | MACS-3949 (C) | STOT//ALTAR84/ALD/3/THB/CEP7780//2\*MUSK4 |
| 4 | NIDW-1149 (C) | NIDW-295 X NIDW-15 |
| 5 | AKDW-2997-16 (C) | CPAN6140/RAJ1555 |
| 6 | NIDW-1569 | SOOTY\_9/RASCON\_37//GUAYACAN INIA/11/BOOMER\_33/ZAR/3/BRAK\_2/AJAIA\_2//SOLGA\_8/10/PLATA\_10/6/MQUE/4/USDA573//QFN/AA\_7/3/ALBA-D/5/AVO/HUI/7/PLATA\_13/8/THKNEE\_11/9/CHEN/ALTAR 84/3/HUI/POC//BUB/RUFO/4/FNFOOT/12/PLATA\_7/ILBOR\_1//SOMAT\_3/3/SORA/2\*PLATA\_12//S |
| 7 | NIDW-1572 | MÂALI/6/MUSK\_1//ACO89/FNFOOT\_2/4/MUSK\_4/3/PLATA\_3//CREX/ALLA/5/OLUS\*2/ILBOR//PATKA\_7/YAZI\_1/10/SELIM/9/ALTAR84/860137//YAZI\_1/4/LIS\_8/FILLO\_6/3/FUUT//HORA/JOR/8/GEDIZ/FGO//GTA/3/SRN\_1/4/TOTUS/5/ENTE/MEXI\_2//HUI/4/YAV\_1/3/LD357E/2\*TC60//JO69/6/SOMBRA |
| 8 | NIDW-1573 | MÂALI/6/MUSK\_1//ACO89/FNFOOT\_2/4/MUSK\_4/3/PLATA\_3//CREX/ALLA/5/OLUS\*2/ILBOR//PATKA\_7/YAZI\_1/10/SELIM/9/ALTAR84/860137//YAZI\_1/4/LIS\_8/FILLO\_6/3/FUUT//HORA/JOR/8/GEDIZ/FGO//GTA/3/SRN\_1/4/TOTUS/5/ENTE/MEXI\_2//HUI/4/YAV\_1/3/LD357E/2\*TC60//JO69/6/SOMBRA |
| 9 | NIDW-1574 | P91.272.3.1/3\*MEXI75//2\*JUPARE C 2001/11/BOOMER\_33/ZAR/3/BRAK\_2/AJAIA\_2//SOLGA\_8/10/PLATA\_10/6/MQUE/4/USDA573//QFN/AA\_7/3/ALBA- \_11/9/CHEN/ALTAR84/3/HUI/POC//BUB/RUFO/4/FNFOOT/12/STR/4/JO69/3/JO69/CRA//CIT71/5/ALTAR 84/ |
| 10 | NIDW-1576 | ALAS/5\*SILVER\_2/4/2\*ARMENT//SRN\_3/NIGRIS\_4/3/CANELO\_9.1/6/YAZI\_1/AKAKI\_4//SOMAT\_3/3/AUK/GUIL//GREEN/5/2\*NETTA\_4/DUKEM\_12//RASCON\_19/3/SORA/2\*PLATA\_12/4/GREEN\_18/FOCHA\_1//AIRON\_1/7/C F4 20 S/4/YAZI\_1/AKAKI\_4//SOMAT\_3/3/AUK/GUIL//GREEN/5/CANELO\_9.1//SH |
| 11 | NIDW-1578 | SIMETO/3/SORA/2\*PLATA\_12//SRN\_3/NIGRIS\_4/5/TOSKA\_26/RASCON\_37//SNITAN/4/ARMENT//SRN\_3/NIGRIS\_4/3/CANELO\_9.1/11/BRONTE/4/ARMENT//SRN\_3/NIGRIS\_4/3/CANELO\_9.1/10/RCOL/THKNEE\_2/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV\_1/6/ARDENTE/7/HUI/YAV79/8/POD\_9 |
| 12 | NIDW-1579 | SOMAT\_4/INTER\_8/5/AJAIA\_16//HORA/JRO/3/GAN/4/ZAR/9/GEDIZ/FGO//GTA/3/SRN\_1/4/TOTUS/5/ENTE/MEXI\_2//HUI/4/YAV\_1/3/LD357E/2\*TC60//JO69/6/SOMBRA\_20/7/JUPARE C2001/8/CS/TH.CU//GLEN/3/GEN/4/MYNA/VUL/5/2\*DON87/6/2\*BUSCA\_3 |
| 13 | NIDW-1582 | MÂALI/6/MUSK\_1//ACO89/FNFOOT\_2/4/MUSK\_4/3/PLATA  3//CREX/ALLA/5/OLUS\*2/ILBOR//PATKA\_7/YAZI\_1/10/SELIM/9/ALTAR84/860137//YAZI\_1/4/LIS\_8/FILLO\_6/3/FUUT//HORA/JOR/8/GEDIZ/FGO//GTA/3/SRN\_1/4/TOTUS/5/ENTE/MEXI\_2//HUI/4/YAV\_1/3/LD357E/2\*TC60//JO69/6/SOMBA |
| 14 | NIDW-1555 | MOHAWK/6/LOTUS\_5/F3LOCAL(SEL.ETHIO.135.85)/5/CHEN/ALTAR84/3/HUI/POC//BUB/RUFO/4/FNFOOT/7/SORA/2\*PLATA\_12/3/SORA/2\*PLATA\_12//SOMAT\_3/4/AJAIA\_13/YAZI//DIPPER\_2/BUSHEN\_3 |
| 15 | NIDW-1561 | CPAN 1783//V 86/HI 8671/3/IMMER/ GRI// RAJ 1555 |
| 16 | NIDW-1542 | NIDW 295 X HI 8750 |
| 17 | NIDW-1556 | CIT71/DIPPER\_1//ARIZA\_2/3/PROZANA/ARLIN//MUSK\_6/4/TATLER\_1/TARRO\_1//HYDRANASSA30/SILVER\_5/10/PLATA\_3//CREX/ALLA/3/SORA/2\*PLATA\_12/4/RASCON\_37/GREEN\_2/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV\_1/6/ARDENTE/7/HUI/YAV79/8/POD\_9/11/ALTAR 84/STINT//SILVE |
| 18 | NIDW-1557 | 1A.1D5+106/3\*WB881/6/CHEN\_1/TEZ/3/GUIL//CIT71/CII/4/SORA/PLATA\_12/5/STOT//ALTAR84/ALD/7/DUKEM\_1//PATKA\_7/YAZI\_1/3/PATKA\_7/YAZI\_1/9/CBC509CHILE/6/ECO/CMH76A.722//BIT/3/ALTAR84/4/AJAIA\_2/5/KJOVE\_1/7/AJAIA\_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA\_13/8/ |
| 19 | NIDW-1520 | HI 8692 X GW 1189 |
| 20 | NIDW-1534 | ADAMAR\_15//ALBIA\_1/ALTAR 84/3/SNITAN/4/SOMAT\_4/INTER\_8/5/SOOTY\_9/RASCON\_37/6/BICHENA/AKAKI\_7/4/LIS\_8/FILLO\_6/3/FUUT//HORA/JOR/5/YAZI\_1/AKAKI\_4//SOMAT\_3/3/AUK/GUIL//GREEN/7/TOPDY\_18/FOCHA\_1//ALTAR 84/3/AJAIA\_12/F3LOCAL(SEL.ETHIO.135.85)//PLATA\_13/4/ |
| 21 | NIDW-1499 | GW 1189 X NIDW 295 |

**2.1 Observation Recorded:**

Crude Protein

The protein content was determined by Micro-Kjeldahl method (Anonymous, 2000).

Crude Fibre

The crude fibre was estimated by employing the standard method of analysis (AOAC 2000)

Crude fat

The crude fat content was determined by ether extraction using Soxhlet apparatus (AOAC, 2000).

Minerals

Iron, zinc and other minerals were determined according to the standard method of AOAC (2000) using flame Atomic Absorption Spectrophotometer.

**2.2 Statistical analysis**

Mean values were subjected to analysis of variance to test the significance for each character as per methodology advocated by Panse and Sukhatme’s methodology (1995). GCV and PCV was calculated by the formula given by Burton (1952), heritability in broad sense (h2) by Hanson *et al.* (1956) and genetic advance i.e. the expected genetic gain was calculated by using the procedure given by Allard (1960).

**3. Results and Discussion:**

**3.1: Mean Performance and Analysis of Variance**

The analysis of variance for nine characters is presented in Table 3. For all characters studied, there were significant variances among the genotypes, revealing a vast range of variation in sixteen genotypes of macaroni wheat along with five standard checks. The analysis of variance indicated that wide variability among the genotypes. This indicates that considerable amount of variation persist for all the characters and considerable improvements can be achieved by selection for these characters.

The mean performance of sixteen macaroni wheat genotypes over the five standard checks, on nine nutritional characters is studied and presented in Table 2. The variation in protein percentage ranged between 10.30 % and 13.83 %. Genotype NIDW-1582 showed highest (13.83 %) followed by NIDW-1555 (12.99 %) and NIDW-1556 (12.38%) protein content. When iron content compared to the standard check AKDW-2997-16 (5.03) genotypes NIDW-1582 (6.11), NIDW-1555 (5.32), NIDW-1556 (5.38 mg/100 g), NIDW-1569 (5.11 mg/100 g) and NIDW-1499 (5.2 mg/100 g) were found significantly superior for iron content while genotype NIDW-1579 (5.04 mg/100 g) was at par with standard check. The mean for zinc content was recorded 3.03 mg/100 g. genotype NIDW-1555 (3.82 mg/100 g) exhibited highest zinc content followed by NIDW-1582 and NIDW-1556 (3.52 mg/100 g) each while the lowest zinc content was recorded in genotypes NIDW-1542 (2.04 mg/100 g) followed by NIDW-1574 (2.21 mg/100 g). For fat content (%) the standard check MACS-3949 (1.52 %) genotype NIDW-1579 (1.99 %) was found significantly superior for fat content (%) while genotypes NIDW-1572 (1.58 %) and NIDW-1542 (1.57 %) were at par with standard check. Genotype NIDW-1579 recorded highest fiber content value (1.90 %). The genotypes NIDW-1569 showed highest calcium content (42.53 mg/100 g) followed by NIDW-1555 (41.41 mg/100 g) and NIDW-1556 (41.20 mg/100 g).The general mean value for magnesium content in twenty-one wheat genotypes was 132.08 mg/100g. Genotype NIDW-1556 (137.57 mg/100 g) exhibited highest magnesium content followed by NIDW-1555 (136.66 mg/100 g). Genotype NIDW-1499 (0.64 mg/100 g) exhibited highest copper content. Genotype NIDW-1557 (3.95 mg/100 g) exhibited highest sodium content followed by NIDW-1574 (3.70 mg/100 g).

**Table: 2 Mean Performance of twenty one wheat genotypes for nutritional characters.**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SN** | **Name of Genotype** | **Protein Content (%)** | **Fat Content (%)** | **Fiber Content (%)** | **Fe (mg/100g )** | **Zn (mg/100g)** | **Ca (mg/100g)** | **Mg**  **(mg/100g)** | **Cu**  **(mg/100g )** | **Na**  **(mg/100g )** |
| 1 | Panchavati (C) | 11.93 | 1.16 | 1.35 | 4.83 | 3.09 | 38.08 | 132.87 | 0.60 | 2.50 |
| 2 | Godavari (C) | 11.97 | 1.33 | 1.35 | 4.88 | 3.22 | 38.23 | 135.97 | 0.58 | 2.49 |
| 3 | MACS-3949(C) | 11.96 | 1.52 | 1.48 | 4.93 | 3.23 | 40.24 | 133.47 | 0.57 | 2.32 |
| 4 | NIDW-1149 (C) | 11.77 | 1.42 | 1.32 | 4.45 | 3.25 | 37.71 | 132.87 | 0.54 | 2.61 |
| 5 | AKDW-2997-16 (C) | 12.05 | 1.42 | 1.49 | 5.03 | 3.12 | 38.90 | 133.73 | 0.56 | 2.31 |
| 6 | NIDW-1569 | 12.10 | 1.34 | 1.67 | 5.11 | 3.45 | 42.53 | 134.73 | 0.62 | 2.29 |
| 7 | NIDW-1572 | 11.07 | 1.58 | 1.09 | 3.55 | 2.55 | 35.47 | 127.53 | 0.39 | 3.30 |
| 8 | NIDW-1573 | 11.50 | 1.47 | 1.17 | 4.10 | 2.99 | 32.90 | 131.57 | 0.51 | 2.86 |
| 9 | NIDW-1574 | 10.95 | 1.16 | 1.05 | 3.55 | 2.21 | 35.37 | 126.10 | 0.35 | 3.70 |
| 10 | NIDW-1576 | 10.30 | 1.55 | 1.13 | 3.56 | 2.82 | 36.60 | 120.03 | 0.33 | 3.12 |
| 11 | NIDW-1578 | 11.47 | 1.40 | 1.16 | 3.95 | 2.84 | 36.56 | 131.37 | 0.50 | 3.01 |
| 12 | NIDW-1579 | 12.06 | 1.99 | 1.90 | 5.04 | 3.29 | 40.30 | 134.37 | 0.56 | 2.31 |
| 13 | NIDW-1582 | 13.83 | 1.37 | 1.78 | 6.11 | 3.52 | 40.36 | 135.53 | 0.62 | 2.04 |
| 14 | NIDW-1555 | 12.99 | 1.13 | 1.80 | 5.32 | 3.82 | 41.41 | 136.33 | 0.63 | 2.03 |
| 15 | NIDW-1561 | 11.70 | 1.14 | 1.26 | 4.27 | 3.05 | 37.63 | 132.67 | 0.52 | 2.20 |
| 16 | NIDW-1542 | 11.37 | 1.57 | 1.15 | 3.65 | 2.04 | 36.49 | 131.00 | 0.49 | 3.11 |
| 17 | NIDW-1556 | 12.38 | 1.16 | 1.73 | 5.38 | 3.45 | 41.20 | 137.57 | 0.63 | 2.20 |
| 18 | NIDW-1557 | 11.26 | 1.33 | 1.13 | 3.63 | 2.81 | 36.39 | 129.37 | 0.46 | 3.95 |
| 19 | NIDW-1520 | 11.53 | 1.52 | 1.20 | 4.23 | 3.03 | 36.68 | 132.30 | 0.52 | 2.70 |
| 20 | NIDW-1534 | 11.25 | 1.42 | 1.03 | 3.63 | 2.55 | 36.14 | 129.27 | 0.40 | 3.12 |
| 21 | NIDW-1499 | 12.16 | 1.42 | 1.55 | 5.20 | 3.33 | 40.63 | 134.90 | 0.64 | 2.23 |
|  | Mean | 11.79 | 1.46 | 1.37 | 4.49 | 3.03 | 38.09 | 132.08 | 0.53 | 2.69 |
|  | Range | 10.30-13.83 | 1.13-1.99 | 1.03-1.90 | 3.55-6.11 | 2.04-3.82 | 32.90-42.53 | 120.03-137.57 | 0.33-0.64 | 2.03-3.95 |
|  | S.E. ± | 0.192 | 0.022 | 0.022 | 0.023 | 0.019 | 0.029 | 0.905 | 0.002 | 0.013 |
|  | C. D. 5% | 0.548 | 0.065 | 0.065 | 0.065 | 0.056 | 0.085 | 2.588 | 0.008 | 0.038 |
|  | C.V. | 2.820 | 2.709 | 2.875 | 0.886 | 1.136 | 0.135 | 1.187 | 0.957 | 0.873 |

**Table 3. Analysis of variance for nine different nutritional characters in macaroni wheat**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr. No.** | **Characters** | **Mean sum of squares** | | |
| **Replication (1)** | **Genotype (39)** | **Error (39)** |
| 1 | Protein Content (%) | 0.289 | 1.633\*\* | 0.110 |
| 2 | Fat Content % | 0.0006 | 0.208\*\* | 0.001 |
| 3 | Fiber content % | 0.002 | 0.222\*\* | 0.001 |
| 4 | Fe (mg/100 g) | 0.0007 | 1.719\*\* | 0.001 |
| 5 | Zn (mg/100 g) | 0.002 | 0.561\*\* | 0.001 |
| 6 | Ca (mg/100 g) | 0.0006 | 17.931\*\* | 0.002 |
| 7 | Mg (mg/100 g) | 5.831 | 48.145\*\* | 2.459 |
| 8 | Cu (mg/100 g) | 0.00002 | 0.027\*\* | 0.00002 |
| 9 | Na (mg/100 g) | 0.0003 | 0.880\*\* | 0.0005 |

\* and \*\* indicate significant at 5 and 1 per cent level, respectively.

**3.2: Genotypic and Phenotypic Coefficients of Variation**

Estimates of genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV), heritability (broad sense), genetic advance and genetic advance of percent mean for nine characters are presented in Table 4. Genotypic coefficient of variation (GCV) was highest for sodium content (20.16 %) followed by Fiber content (19.79%), Cu content (18.10 %) and Fat content (17.98 %). The character Mg content (2.95%) recorded lowest GCV. The maximum phenotypic coefficient of variation (PCV) was recorded for Na content (20.18 %), followed by Fiber content (20.00 %) and Fat content (18.18 %). Similar results were obtained by Kaur *et al.* (2008). The high genotypic coefficient of variation and phenotypic coefficient of variation was observed for Na content. Moderate genotypic coefficient of variation and phenotypic coefficient of variation was observed for fat content (17.98 and 18.18%), fibre content (19.79 and 20.00%), Fe content (16.83 and 16.86 mg/100 g), Zn content (14.26 and 14.31 mg/100 g) and copper content (18.10 and 18.13 mg/100 g). Low genotypic coefficient of variation and phenotypic coefficient of variation was observed for protein content (6.66 and 6.66%), Ca (6.41 and 6.42 mg/100 g) content and Mg content (2.95 and 3.18 mg/100g). In general “the magnitude of phenotypic coefficient of variation was higher than the genotypic coefficient of variation which reflects the influence of environment on the expression of traits”, Kaur *et al.* (2008), Majumder *et al*. (2008) and Imran *et al.,* (2018). found the similar results.

**3.3: Heritability and Genetic Advance**

Heritability and Genetic Advance are important selection parameters. High estimates of heritability (>60%) was recorded for all studied characters. The highest estimates of heritability exhibited in Ca content (99.96%) followed by Na content (99.81%), Fe content (99.72) and Cu content (99.72%) each (Table 4). Kumar *et al.,* (2013) and Taneva et al., (2019).

The range of genetic advance observed from 0.19 to 7.45. The highest estimates of GA exhibited for Mg content (7.45) followed by Ca content (5.03) and Fe content (1.55). While the lowest estimates of GA was recorded for Cu content (0.19). Imran *et al.,* (2018).

High estimates of genetic advance as per cent of mean observed for Na content (41.49 %), followed by fiber content (40.35 %), Cu content (37.25 %), fat content (36.63 %) and Fe content (34.63 %). While Mg content (5.64 %) showed the lowest performance in genetic advance as per cent of mean. High heritability coupled with high genetic advance as per cent of mean was observed for all characters except Protein content (81.25%), Ca content (13.21 mg/100 g) and Mg content (5.64 mg/100 g) indicating that these traits were predominantly governed by additive gene action and suggesting that the selection of these trait would be effective for the desired genetic improvement in early segregating generations for these traits. Similar findings have been reported by Taneva *et. al* 2019 and Imran *et al.,* (2018).

**Table 4: Estimates of variability parameters for nutritional characters in macaroni wheat**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **SN.** | **Character** | **Mean** | **Range** | **GCV (%)** | **PCV (%)** | **ECV (%)** | **Heritability**  **(bs) (%)** | **Genetic Advance** | **Genetic Advance**  **% of Mean** |
| 1 | Protein Content (%) | 11.79 | 10.30 to 13.83 | 6.04 | 6.66 | 2.82 | 82.12 | 1.33 | 11.28 |
| 2 | Fat Content % | 1.46 | 1.13 to 1.99 | 17.98 | 18.18 | 2.70 | 97.78 | 0.53 | 36.63 |
| 3 | Fiber content % | 1.37 | 1.03 to 1.90 | 19.79 | 20.00 | 2.87 | 97.93 | 0.55 | 40.35 |
| 4 | Fe (mg/100 g) | 4.49 | 3.55 to 6.11 | 16.83 | 16.86 | 0.88 | 99.72 | 1.55 | 34.63 |
| 5 | Zn (mg/100 g) | 3.03 | 2.04 to 3.82 | 14.26 | 14.31 | 1.13 | 99.37 | 0.88 | 29.30 |
| 6 | Ca (mg/100 g) | 38.09 | 32.90 to 42.53 | 6.41 | 6.42 | 0.13 | 99.96 | 5.03 | 13.21 |
| 7 | Mg (mg/100 g) | 132.08 | 120.03 to 137.57 | 2.95 | 3.18 | 1.18 | 86.09 | 7.45 | 5.64 |
| 8 | Cu (mg/100 g) | 0.53 | 0.33 to 0.64 | 18.10 | 18.13 | 0.95 | 99.72 | 0.19 | 37.25 |
| 9 | Na (mg/100 g) | 2.69 | 2.03 to 3.95 | 20.16 | 20.18 | 0.87 | 99.81 | 1.11 | 41.49 |

**3.4: Correlation Studies:**

**1) Protein content (%)**

Protein content showed significant positive correlation with fiber content (rp = 0.759, rg = 0.862), Fe content (rp = 0.864, rg = 0.956), Zn content (rp = 0.705, rg = 0.792), Ca content (rp = 0.644 rg =0.735), Mg content (rp = 0.755 rg =0.882). Similar results reported by Peleg *et al.* (2009) Table 5. Similar findings reported by Galterio et al. (2001) and Peleg *et al.* (2009)

**2) Fat content (%)**

Fat content showed non-significant positive correlation with fiber content (rp = 0.078 rg = 0.081) and calcium content (rp= 0.026 rg= 0.026)

**3) Fiber content (%)**

Fiber content showed positive and significant association with protein content (rp = 0.759 rg = 0.862), Fe content (rp = 0.905 rg = 0.915), Zn content (rp = 0.825 rg = 0.837), Ca content (rp = 0.872 rg = 0.881) , Mg content (rp = 0.702 rg = 0.748) Cu content (rp = 0.835 rg = 0.845) at both phenotypic and genotypic level. Similar findings reported by Amiri *et al*. (2018), Biel *et al.* (2021) and Okereke *et al.* (2021).

**4) Fe content (mg/100 g)**

Iron content showed significant positive correlation with protein content, (rp = 0.864 (rg = 0.956), fiber content (rp = 0.905 rg = 0.915), zinc content (rp = 0.867 rg = 0.871), calcium content (rp = 0.831 rg = 0.832), magnesium (rp = 0.777 rg = 0.836), copper content (rp = 0.905 rg = 0.908) at both genotypic and phenotypic level. Suchowilska *et al*. (2012) and Badakhshan *et al*. (2013) observed the similar results.

**5) Zn content (mg/100 g)**

Zinc content showed significant positive correlation with protein content (rp = 0.705 rg = 0.792), fiber content (rp = 0.825 rg =0.837), iron content (rp = 0.867 rg = 0.871), calcium content (rp = 0.753 rg = 0.756), magnesium (rp = 0.664 rg = 0.716), copper content (rp=0.817 rg = 0.820) at both phenotypic and genotypic level. The finding for zinc and iron correlation are in consistent with the findings of) Badakhshan *et al*. (2013) Pandey *et al*. (2016) and Cakmak *et al.* (2018).

**6)** **Ca content (mg/100 g)**

Calcium content showed significant positive correlation with protein content (rp = 0.664 rg = 0.735), fiber content (rp = 0.872 rg =0.881), iron content (rp = 0.831 rg = 0.832), zinc content (rp = 0.753 rg = 0.756), magnesium (rp = 0.629 rg = 0.677), copper content (rp = 0.894 rg = 0.780) at both phenotypic and genotypic level. Hussain *et al.,* (2012) and Biel *et al.* (2021) observed the similar results.

**7)** **Magnesium content (mg/100 g)**

Magnesium content showed significant positive correlation with protein content (rp = 0.755 rg = 0.882), fiber content (rp = 0.702 rg =0.748), iron content (rp = 0.777 rg = 0.836), zinc content (rp = 0.664 rg = 0.716), calcium (rp = 0.629 rg = 0.677), copper content (rp = 0.778 rg = 0.963) at both genotypic and phenotypic level. While significant negative correlation with sodium content (rp = -0.748 rg = -0.774) at both genotypic and phenotypic level. These results are in consistent with the results of Rakhi and Punia (2013) and Biel *et al.* (2021).

**8) Copper content (mg/100 g)**

Copper content showed significant positive correlation with protein content (rp = 0.797 rg = 0.877), fiber content (rp = 0.835 rg =0.845), iron content (rp = 0.905 rg = 0.908), zinc content (rp = 0.817 rg = 0.820), magnesium content (rp = 0.778 rg = 0.963) at both genotypic and phenotypic level. While significant negative correlation with sodium content (rp = -0.848 rg = -0.849) at both phenotypic and genotypic level. Similar findings reported by Pandey *et al*. (2016).

**9) Sodium content (mg/100 g)**

Sodium content showed significant negative correlation with protein content (rp = -0.725 rg = -0.796), fiber content (rp = -0.795 rg = -0.807), iron content (rp = -0.875 rg = -0.877), zinc content (rp = -0.818 rg = -0.821), magnesium (rp = -0.748 rg = -0.774), copper content (rp = -0.848 rg = -0.849) at both phenotypic and genotypic level.

Thus the significant positive correlation was found between protein content (%) with fiber content (%) and all minerals except Na content (mg/100 g) at both genotypic and phenotypic level. This indicates that simultaneous improvement of these characters through selection. While fat content (%) shown non-significant negative correlation with protein content (mg/100 g). In present investigation genotypic correlation were higher than phenotypic correlation for most of the studied characters. This indicates that there was high degree of association among two variables at genotypic level; its phenotypic expression was deflected due to influence of environment (Table 5).

**4. Conclusion:**

Genetic variability among the genotypes is thought to be a valuable source to develop the better crop varieties for its commercialization. In present study, significant differences were observed for the studied nine nutritional traits of the macaroni wheat. Correlation for most of the characters at both genotypic and phenotypic levels was made to resolve the direction of magnitude of association among characters. The significant positive correlation was found between protein content (%) with fiber content (%) and all minerals except sodium content (mg/100g) at both genotypic and phenotypic level. This indicates that simultaneous improvement of these characters through selection. While fat content (%) shown non-significant negative correlation with protein content (mg/100 g). The performance of macaroni wheat genotypes for nutritional parameters following genotypes *viz.,* NIDW-1556, NIDW-1555, NIDW-1569, NIDW-1499 and NIDW-1579 used for protein, Iron and zinc content, NIDW-1582 (for protein content), NIDW-1569 (for calcium content), NIDW-1556 (for Mg content) and NIDW-1499 (for Cu content) can be used in future breeding programme for development of new biofortified varieties in macaroni wheat.

**Table 5: Estimates of phenotypic (above the diagonal) and genotypic (below the diagonal) correlation coefficients among nutritional characters.**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Sr.No.** | **Name of character** | **Protein**  **(%)** | **Fat %** | **Fiber %** | **Fe** | **Zn** | **Ca** | **Mg** | **Cu** | **Na** |
| 1. | **Protein (%)** | **1.000** | -0.114 | 0.759\*\* | 0.864\*\* | 0.705\*\* | 0.664\*\* | 0.755\*\* | 0.797\*\* | -0.725\*\* |
| 2. | **Fat %** | -0.119 | **1.000** | 0.078 | -0.029 | -0.097 | 0.026 | - 0.022 | -0.013 | -0.070 |
| 3. | **Fiber %** | 0.862\*\* | 0.081 | **1.000** | 0.905\*\* | 0.825\*\* | 0.872\*\* | 0.702\*\* | 0.835\*\* | -0.795\*\* |
| 4. | **Fe** | 0.956\*\* | -0.029 | 0.915\*\* | **1.000** | 0.867\*\* | 0.831\*\* | 0.777\*\* | 0.905\*\* | -0.875\*\* |
| 5. | **Zn** | 0.792\*\* | -0.103 | 0.837\*\* | 0.871\*\* | **1.000** | 0.753\*\* | 0.664\*\* | 0.817\*\* | -0.818\*\* |
| 6. | **Ca** | 0.735\*\* | 0.026 | 0.881\*\* | 0.832\*\* | 0.756\*\* | **1.000** | 0.629\*\* | 0.894\*\* | -0.719\*\* |
| 7. | **Mg** | 0.882\*\* | -0.042 | 0.748\*\* | 0.836\*\* | 0.716\*\* | 0.677\*\* | **1.000** | 0.778\*\* | -0.748\*\* |
| 8. | **Cu** | 0.877\*\* | -0.014 | 0.845\*\* | 0.908\*\* | 0.820\*\* | 0.780\*\* | 0.963\*\* | **1.000** | -0.848\*\* |
| 9. | **Na** | -0.796\*\* | -0.069 | -0.807\*\* | -0.877\*\* | -0.821\*\* | -0.749\*\* | -0.774\*\* | -0.849\*\* | **1.000** |

\*and\*\* significant at P=5 and P=1 level of significance,

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