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RESEARCH ARTICLE

ELICITATION OF HIGH-QUALITY AND YIELD IN BREAD WHEAT (TRITICUM AESTIVUM L.) MUTANT LINES IMPROVED BY GAMMA RAYS

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Abstract

The study was carried out to assess quality traits and grain yield of bread wheat mutant lines using an augmented experimental design in the 2014-2015 growing season. Considering the results of the experiment, large variations were noted between the means of mutant lines for PC (12.49-16.24%), ZSV (25.55-59.05 mL), WGC (26.76-39.06%), AE (227.3-343.3 10^{-4} joule), QI (2.104-4.196), TGW (34.1-55.9 g), TW (75.94-83.04 kg hl^{-1}) and GY (4712-9715 kg ha^{-1}). The 15 lines for GPC, 16 lines for ZSV, 13 lines for WGC, 15 lines for AE, 18 lines for QI, 30 lines for TGW, 11 lines for TW and 10 lines for GY have been found to perform compared to the parents. On the results of the quality traits, MT8, MT4, MT5, MT6, MT23, MT24, MT25, MT41, MT50 and MT51 were the best quality mutant lines for protein amount and quality, while the mutant lines with the best performance for grain yield were MT53, MT14, MT20, MT33, MT35, and MT19. By evaluating the research results together, it was determined that the mutant lines MT53, MT14, MT35 and MT11 had the best grain yield and quality performances. The better performances of mutant lines derived from generally well-adapted commercial parental genotypes indicate that they are the appropriate source material for mutation breeding. The mutant lines (MT53, MT14, MT35, MT20, MT33, MT11 and MT19) were selected for yield trials, and the high quality mutant lines were added to the genetic stock to be used for wheat quality improvement.

Introduction:-

Wheat is a major cereal crop for both human and animal nutrition. It is a major source of energy, protein, and dietary fibre in human nutrition and animal feeding. It provides 28% of the world's edible dry matter and up to 60% of the daily calorie intake of the world's population (FAOSTAT, 2021), it is the most essential food resource for one-third of the population all around the world (Akbarnia and Azar-Abad, 2011). Nutritionally, wheat is an important source of dietary protein, carbohydrates, the B complex of vitamins, vitamin E, iron, trace minerals, and fibre (Shewry, 2009). This explains why specific research that has focused on wheat breeding studies for over a century emphasizes the importance of wheat quality in determining final product characteristics while evaluating wheat quality characteristics alongside grain yield is essential. Thus, population growth and improvements in living conditions require the continuation of breeding efforts for an increase in wheat grain yield and quality.

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Mutation breeding may help in reaching the goal of the breeding program faster than that of conventional breeding (Chakraborty andPaul, 2013). Mutation breeding has become an appropriate option to improve plant characters when conventional breeding does not work, or the desired traits were recessive, or improving another character in an established plant variety, or improving one or two main character(s) (Harten, 1998;Ahloowalia andMaluszynski,2001). Besides, mutagenesis can isolate mutants with multiple characters, as compared to transgenesis where the only line can be introduced, it's the major advantage of inducing mutations (Louali et al., 2015)**.** Mutation breeding can be applied to improve a specific character without changing other characters. Furthermore, it may create a new character that did not belong to parental plants.

Physical mutagen such as gamma irradiation may be used in changing the genetic constitution of plant genome towards the desired character with high genetic variability (Mak et al.,1996;Ishak, 2000). The mutants developed in wheat have a great potential for direct release and inclusion in hybridization breeding programs (Sakin et al., 2005). A huge number of these mutant cultivars have been released in developing regions boosting the economic status of these countries. The released mutant cultivars in different crops are covering hundreds of millions of ha of agricultural land, had a great economic impact on agriculture and food production and added billions of dollars to the economy of many countries (Jain,2006). Mutation, a traditional plant breeding method, leads to the increase of germplasm variability and use, and the development of new varieties with desired traits (Burrows et al., 2001). Gamma rays, in particular, is a wellknown physical mutagen and are often used in mutation breeding program to induce desirable mutants with different genotypes (Konzak, 1987;Knott,1991). Up to the 90s of the pastcentury, the mutagenesis accounted for the development of 80 wheat, 74 barley and 13 oat varieties (Mahan, 1989) and over 3332 varieties from direct mutant lines or their crosses in 228 plants species in 73 countries globally (FAO/IAEA,2018). The mutant varieties are improved for a differenttraits such as resistance to biotic stress (557), tolerance to abiotic stress (248), increased yield and yield components (1029), quality and nutrition traits (1173), and agronomic and botanic traits (2981) (Mir et al., 2020).

The goal of a wheat breeding program is to develop superior genotypes as a result of many years of selection. Early-stage advanced generation selection is based on visual observations of yield components, disease resistance, tillering potential, lodging resistance and seed quality. In the stage of the selection process, there could be an insufficient seed of the new treatments' to undertake replicated experiments or the number of genotypes could be very large to manage in terms of resources. Therefore, augmented designs have been developed for the evaluation of genotypes in the early stages of a breeding program (Federer,1956). Augmented designs consist of two kinds of treatments, the checks or the standard treatments and new or augmented treatments. The design presumes checks as fixed effects whereas the new entries as random effects. The new entries are usually not replicated owing to a large number of entries initially in a breeding programme, especially when dealing with large germplasm sets. However, the checks are replicated to act as points of reference. More sophisticated augmented designs allow for the adjustment of test varieties by rows and columns (Federer andRaghavarao,1975; Lin and Poushinsky, 1983). The efficiency of the analysis over another is usually measured in terms of reduced error variance, expected error mean square or average standard error of the difference between genotype means (Cochran and Cox, 1957;Binns,1987;Magnussen,1990). The average standard error of the difference (SED) was reported to be more appropriate since it is used for comparison among genotypes using the same scale as the traits (Binns, 1987;Cullisand Gleeson, 1991; Gleeson,1997). The study aims to determine the promising cultivar candidates with high commercial value by evaluating the protein amount and quality and grain yield of mutant lines developed from bread wheat with different characteristics, and even to enable the selection of new mutant lines that can be used as source material for special purposes such as high quality in wheat breeding programs.

Material and Methods:-

Experimental site and growing conditions: This study was conducted at the University of TekirdağNamık Kemal, Faculty of Agriculture, Department of Field Crops, Turkey in the 2014-2015 growing season. Tekirdağ district locates at latitude 40^{o}36'-40^{o}31' and longitude 26^{o}43'-28^{o}08'and altitude is 10 m. The total precipitation was 435.1 mm and the average temperature was 11.5^{O}C during the 2014-2015 wheat growing season (November 2014-June2015) when the experiment was conducted. It is noted that the annual precipitation is about 30 mm lower than the long term average (466 mm) and the average temperature is similar to the long term average (11.5 °C). According to soil analysis results, the experimental area's soil was clay-loam, slightly acidic (pH 6.5), limeless, and poor (1.08%) in the organic matter.

Experimental materials, gamma irradiation and design: Four bread wheat (*Triticumaestivum*L.) genotypes including one advanced line (IBWSN4), one foreign variety (Avustralya), and two well-adapted commercial variety (Bezostaja 1 and Kate A-I), were used as the parent material. The moisture contents of seeds of the genotypes were 12.1% for Avustralya, 11.4% for Bezostaja 1, 11.7% for Kate A-I and 12.0% for IBWSN4. Gamma treatment was obtained from ^{60}Cobalt, Ob-Servo Sanguis Co-60 Research Irradiator with isotope model, while the dose rate was 2.190 kGy h^{-1}before the 2009-2010 growing season sowing at the Turkish Atomic Energy Authority, Sarayköy Nuclear Research and Training Center, Ankara, Turkey. Right after irradiation, the experiment was set up using a total of 20 M_0(100, 200, 300, 400 and 500 Gy) combination seeds together with the un-irradiated (control) in the experimental field of the Field Crops Department of the Faculty of AgricultureofTekirdağNamıkKemalUniversityduringthegrowingseasonof2009-2010. The seeds obtained from the harvested plants in M_1generation were sown in 2010-11 (M_2), 2011-12 (M_3) and 2012-13 (M_4) growing seasons.

Table 1:- The experiment material of the study.

C1 (Bezostaja 1)	MT12 (400 Gy)	MT19 (200 Gy)	MT35 (400 Gy)	MT46 (300 Gy)	MT57 (200 Gy)
MT1 (100 Gy)	MT13 (400 Gy)	MT20 (200 Gy)	MT36 (400 Gy)	MT47 (300 Gy)	MT58 (200 Gy)
MT2 (100 Gy)	MT23 (500 Gy)	MT21 (200 Gy)	MT37 (400 Gy)	MT48 (300 Gy)	MT59 (200 Gy)
MT3 (100 Gy)	MT24 (500 Gy)	MT22 (300 Gy)	MT38 (400 Gy)	MT49 (400 Gy)	MT60 (300 Gy)
MT4 (100 Gy)	MT25 (500 Gy)	MT27 (300 Gy)	**C3 (Kate A-1)**	MT50 (400 Gy)	MT61 (300 Gy)
MT5 (200 Gy)	MT26 (500 Gy)	MT28 (300 Gy)	MT39 (100 Gy)	MT51 (400 Gy)	MT62 (300 Gy)
MT6 (200 Gy)	**C2 (IBWSN 4)**	MT29 (300 Gy)	MT40 (100 Gy)	MT52 (400 Gy)	MT63 (400 Gy)
MT7 (200 Gy)	MT14 (100 Gy)	MT30 (300 Gy)	MT41 (100 Gy)	MT53 (400 Gy)	MT64 (400 Gy)
MT8 (300 Gy)	MT15 (100 Gy)	MT31 (300 Gy)	MT42 (100 Gy)	**C4 (Avustralya)**	MT65 (400 Gy)
MT9 (300 Gy)	MT16 (100 Gy)	MT32 (400 Gy)	MT43 (200 Gy)	MT54 (100 Gy)	
MT10 (300 Gy)	MT17 (100 Gy)	MT33 (400 Gy)	MT44 (200 Gy)	MT55 (100 Gy)	
MT11 (400 Gy)	MT18 (200 Gy)	MT34 (400 Gy)	MT45 (200 Gy)	MT56 (100 Gy)	
C: check genotype, MT: advanced mutant line					

The experiment was carried out in augmented design with 5 blocks with 65 advanced bread wheat mutant lines of M_6 generation selected from M_4 populations of 4 different bread wheat genotypes and their parents (Table 1) in the 2014-2015 growing season. Each block included 13 advanced bread wheat mutant lines and 4 checks(parents) bread wheat genotypes. Sown were made on Nov. 7, 2014, by hand at the rate of 500 seeds per $m^2$and were 5 m in length, with 2 rows 0.2 m apart. Nitrogen and P_20_5at 140 and 70 kg ha^{-1}, respectively, were incorporated into the soil as compound fertilizer (20-20-0) before sowing, urea during tillering and ammonium nitrate before heading. The crop was kept free of weeds by hand hoeing when necessary.

Grain yield and Grain quality analysis:

After harvest, the grain samples were cleaned and grain yield was calculated based on the moisture content of 14%. Physical characteristics of the grain such as thousand kernel weight (TGW-g) and test weight (TW-kg hl^{-1}) were determined following the official methods of the Approved Methods of the American Association of Cereal Chemists (AACC, 2000). The cleaned samples were conditioned (tempered) overnight to a moisture level of 15% and milled in a Quadrumat Junior Mill (Brabender, GmbH and Co. KG, Duisburg, Germany) to white flour (72% extraction rate), and prepared for chemical analysis. The quantity of grain protein content (GPC) (ICC, 1995) was determined by a near-infrared reflectance spectrophotometer calibrated against Kjeldahl data. Wet gluten quantity (WGC) of wheat flours were analyzed according to the revised standard ICC method No. 155 (ICC, 1994) by using the Glutomatic 2200 system (Perten Instruments AB, Huddinge, Sweden). Zeleny sedimentation value (ZSV) was determined following ICC method No: 166/1 (ICC, 1972). The quality index (ZS/GPC) was expressed as a ratio between the sedimentation value and the content of grain protein according to Halverson and Zeleny (1988). Alveograph W (10^{-4} joules) value was analyzed according to the standard AACC method No. 54-30 (AACC,2009) using Chopin alveograph device.

Statistical Analyses:

The variance analysis on obtained data was performed according to the augmented design using the JUMP 5.0 statistical package program. The differences between the means of the genotypes were determined by the Student-Newman-Keuls test.

Results and Discussion:-

The result of the analysis of variance indicated that the differences between the means of the mutant lines were found to be statistically significant for the quality traits and grain yield. The check (parent) mean performances, the adjusted mean performances of the mutant bread wheat lines calculated taking these into account and the results of the significances test are given in Table 2 for the investigated characters.

Grain Protein Content (GPC) (%):

Grain protein content in wheat is the most important quality criterion (Feil, 1997) and is of great importance in determining the quality and end-use properties of the grain in milling and bakery (Godwin et al., 1999). The most effective data to be used in determining for what purpose wheat will be used is the amount of protein. Considering the character, 65 advanced mutant lines averaged between 16.24-12.49%, while the averages of the checks varied between 14.44-12.90% (Table 2). Among the check genotypes, the lowest and thehighest protein content were determined in Check 3 (Kate A-I) and Check 4 (Avustralya variety) respectively (Table 2). The fifteen mutant lines gave a higher GPC (ranged between 14.46 and 16.24) than the check genotype Avustralya, which has the highest PC. These are MT4, MT5, MT8, MT23, MT24, MT25, MT14, MT35, MT40, MT41, MT50, MT51, MT53, MT56 and MT60. It has been stated that wheat with protein content between 12-14% has ideal bread-making properties (Seçkin,1971), while wheat with a protein content above 14% can be preferred for the production of basic gluten components (Kün, 1988). According to the GPC means of the mother genotypes (Bezostaja1, IBWSN4 and Kate A-I), although the amount of protein in mutant lines increased between 0.31% and 18.15%, reductions in protein ratios were observed in the lines developed from Avustralya.Considering these reference values, it is understood that all of the mutant lines included in the experiment are appropriate in terms of protein content. Our findings are confirmed by the results Corpuz et al. (1983), Li et al. (1994), Sun et al. (1996),Kenzhebayeva et al. (2018),Öztürk et al. (2020)who stated that mutant lines with protein ratios between 0.49% and 21.20% higher than the controls.

Zeleny Sedimentation value (ZSV) (mL):

The sedimentation value, which correlates with gluten content, gluten quality and loaf volume, depends on protein composition and is mostly related to protein content. Therefore, measuring the sedimentation value is useful in quality assessments (Hruskova andFamera, 2003).The quality criteria such as protein and wet gluten that determine the end-use efficiency of wheat are mostly affected by environmental factors content, altitude, location, precipitation amount and distribution, soil fertility, temperature and cultivation technique. However, Zeleny sedimentation value is under the effect of heredity and is mostly affected by genotype (Lorenzo andKronstad, 1987;Grausgruber et al., 2000). In the study, the ZSV of 65 advanced bread wheat mutant lines ranged from 25.55 to 59.05 mL, and the those of check genotypes ranged from 34.20 to 45.00 mL (Table 2). Amongthemutantlines,16lines(MT2, MT4, MT5, MT6, MT8, MT11, MT23, MT24, MT25, MT14, MT41, MT42, MT50, MT51, MT53 and MT56) were higher ZSV than all check genotypes. Regarding the ZSVmeans of the mother genotypes (Bezostaja1 and Kate A-I), although the amount of ZSV in mutant lines increased between 3.12% and 35.53%, reductions in ZSV were observed in the lines developed from IBWSN4 and Avustralya.The Zeleny Sedimentation values are evaluated as > 15 mL weak, 16-24 mL medium, 25-36 mL strong and over 36< very strong gluten (Uluöz,1965). Considering this classification, it is understood that the 12 mutant lines with the highest ZSV values have the strongest gluten proteins. In addition, 30 of the remaining mutant lines were the lines that gave the most appropriate ZSV averages. Our findings are similar to the results of a limited number of previous studies showing that mutagen treatments cause significant changes in ZSV in wheat (Rahemi et al., 2015;Barbu et al., 2018).

Wet Gluten Content (WGC) (%):

Gluten forming proteins play key roles in the baking quality of wheat by improving the water absorption capacity, extensibility and elasticity of the dough (Wieser,2007). The quantity and quality of gluten are considered the most important quality parameters of wheat flour. The gluten content is directly correlated to the grain protein, which is strongly influenced by the pedoclimatic conditions. However, the wheat genotype is considered the most important factor influencing the qualitative characteristics of gluten (Simic et al., 2006).

It has been determined that the 65 advanced bread wheat M_6mutant linestestedexhibitawidevariationforWGCfrom 26.76 to 39.06, while it is ranged between 28.14 to 33.36 for check genotypes (Table 2). Among the tested lines, 13 lines (MT8, MT4, MT5, MT23, MT24, MT25, MT14, MT35, MT40, MT41, MT50, MT51 and MT53) was found to have a higher WGC than the Check 4 (Avustralya) genotype, giving the highest mean (33.36%). When compared with the WGC averages of maternal genotypes; although the WGC values of the Bezostaja1 and Kate A-I mutant lines increased between 0.25% and 24.00%, decreases in WGC were observed in general for the lines developed from

IBWSN4 and Avustralya. When the mutant lines were examined according to the reference values, which were accepted as high gluten values above 35%, 28-35% good, 20-27% moderate and less than 20% gluten content by Ünal (2002), it can be stated that 12 mutant lines have the most suitable wet gluten properties. The gluten content is directly correlated to the grain protein, which is strongly influenced by the pedoclimatic conditions and wheat genotype (Mariani et al., 1995; Bilgin andKorkut, 2005). Any increase in the total protein content of the flour determines a gluten content increase (Perten et al., 1992). The positive relationship between PC and WGC, the results ofCorpuz et al. (1983), Li et al. (1994), Sun et al. (1996),Kenzhebayeva et al. (2018),Öztürk et al. (2020) on the protein content shows that it may be valid in WGC. Our results are supported by the findings ofRahemi et al. (2015), who proved the validity of this situation with their explanations that the mutant developed using gamma rays gave 12.8% higher values for GPC, 22.1% for ZSV and 32.3% higher values for WGC compared to mother variety.

Table 2:- Mean performance of checks and mutant bread wheat lines for quality traits and grain yield.

Genotypes	GPC (%)	ZSV (mL)	WGC	Energy (W)	ZSV/GPC	TGW (g)	TW (kg)	GY (kg ha^{-1})
MT1	13,74 b-n	41,05 b-s	31,36 c-u	240,3 ı-m	2,986 b-p	44,9 k-v	78,62 d-m	7077 a-q
MT2	14,44 a-l	46,05 a-l	33,36 b-o	286,3 a-m	3,166 b-l	41,1 q-y	80,49 a-l	5287 k-q
MT3	13,74 b-n	40,05 c-t	31,76 b-u	234,3klm	2,916 b-q	45,8 e-u	81,49 a-j	6567 c-q
MT4	14,94 a-g	52,05 a-g	34,66 a-ı	343,3 a	3,446 a-d	45,6 e-v	80,33 a-l	6147 f-q
MT5	15,14 a-d	51,05 a-h	35,86 a-d	320,3 a-j	3,336 b-f	53,4 a-d	81,16 a-k	6127 f-q
MT6	12,94 e-n	55,05 ab	29,06 g-u	250,3 g-m	4,196 a	48,8 b-o	82,35 a-g	6877 b-q
MT7	13,64 c-n	40,05 c-t	30,86 c-u	227,3 m	2,936 b-q	50,8 a-k	81,93 a-h	7097 a-q
MT8	16,24 a	59,05 a	39,06 a	336,3abc	3,586 ab	51,6 a-j	82,23 a-g	5777 j-q
MT9	14,14 b-n	44,05 b-q	32,26 b-u	244,3 ı-m	3,096 b-o	48,3 c-p	80,66 a-l	5787 j-q
MT10	13,44 c-n	38,05 e-t	30,96 c-u	240,3 ı-m	2,836 b-q	45,3 h-v	81,01 a-k	6187 f-q
MT11	14,34 a-m	45,05 a-o	33,16 b-o	302,3 a-m	3,126 b-o	46,3 e-u	80,68 a-l	7627 a-o
MT12	14,14 b-n	44,05 b-q	31,86 b-u	232,3klm	3,096 b-o	47,4 c-r	79,00 b-m	7497 a-p
MT13	13,54 c-n	39,05 c-t	30,66 c-u	244,3 ı-m	2,886 b-q	44,2 l-v	82,60 a-d	7317 a-q
MT23	14,96 a-g	49,05 a-ı	35,13 a-e	296,8 a-m	3,259 b-g	48,7 b-p	81,52 a-ı	6482 d-q
MT24	14,56 a-k	46,05 a-l	33,83 a-l	308,8 a-k	3,149 b-m	48,7 b-p	80,02 a-l	5422 k-q
MT25	14,46 a-l	46,05 a-l	33,83 a-l	303,8 a-m	3,169 b-l	47,1 c-s	80,16 a-l	4712 q
MT26	14,06 b-n	44,05 a-q	32,63 b-s	236,8klm	3,119 b-o	47,0 c-s	81,90 a-h	6412 e-q
C1 (check)	13,90 b-n	41,80 b-s	31,68 b-u	273,6 a-m	2,996 b-p	36,9 w-z	80,37 a-l	6074 g-q
MT14	14,46 a-l	46,05 a-l	33,43 a-o	300,8 a-m	3,169 b-l	46,3 e-u	79,44 a-m	9112 a-d
MT15	12,66 j-n	30,05 o-t	28,03 m-u	254,8 f-m	2,389 j-q	44,7 k-v	80,90 a-k	8542 a-ı
MT16	13,36 c-n	33,05 k-t	29,63 e-u	272,8 a-m	2,489 h-q	42,6 n-x	78,44 f-m	7942 a-k
MT17	12,86 h-n	30,05 o-t	28,43 k-u	258,8 b-m	2,349 k-q	36,4 xyz	79,34 a-m	7462 a-p
MT18	12,66 j-n	29,05 q-t	28,03 m-u	251,8 g-m	2,319 m-q	48,5 c-p	81,09 a-k	6482 d-q
MT19	13,76 b-n	37,05 f-t	31,43 b-u	297,8 a-m	2,699 c-q	50,0 a-m	78,62 d-m	9412 ab
MT20	12,96 e-n	35,05 ı-t	29,13 f-u	246,8 h-m	2,709 c-q	50,5 a-l	78,78 c-m	9082 a-d
MT21	12,76 h-n	29,05 q-t	28,13 k-u	253,8 f-m	2,299 opq	52,4 a-ı	79,82 a-m	6822 b-q
MT22	13,26 d-n	32,05 l-t	29,53 e-u	247,8 g-m	2,429 ı-q	46,9 c-s	79,38 a-m	6862 b-q
MT27	13,39 c-n	33,55 j-t	29,66 e-u	273,1 a-m	2,514 f-q	44,7 k-v	79,26 a-m	8582 a-ı
MT28	13,99 b-n	36,55 h-t	31,56 b-u	301,1 a-m	2,614 c-q	49,4 a-n	80,52 a-l	7742 a-n
MT29	12,59 k-n	27,55 st	27,06 p-u	262,1 b-m	2,214 pq	50,5 a-l	79,94 a-m	7892 a-l
MT30	12,49 lmn	36,55 h-t	26,76tu	266,1 a-m	2,934 b-q	49,4 a-n	80,13 a-l	7092 a-q
MT31	12,89 h-n	28,55 rst	28,26 k-u	272,1 a-m	2,234 pq	49,9 a-m	78,38 g-m	7222 a-q
MT32	13,69 c-n	35,55 ı-t	30,86 c-u	331,1 a-j	2,594 e-q	47,3 c-r	77,49 j-m	7932 a-l
MT33	13,29 d-n	30,55 n-t	29,36 e-u	274,1 a-m	2,314 m-q	45,7 e-v	79,65 a-m	9182 abc
MT34	13,79 b-n	38,55 c-t	31,26 c-u	273,1 a-m	2,794 b-q	46,0 e-u	75,94 m	7022 b-q
MT35	14,79 a-g	45,00 a-o	34,06 a-l	326,1 a-j	2,994 b-p	43,2 n-x	76,73 lm	9072 a-e
MT36	12,69 ı-n	29,55 p-t	27,86 m-u	267,1 a-m	2,344 k-q	49,4 a-n	79,57 a-m	6392 f-q
MT37	12,89 h-n	28,55 rst	28,06 k-u	277,1 a-m	2,234 pq	47,9 c-q	79,15 a-m	7072 a-q
MT38	12,29 n	25,55 t	26,96 r-u	269,1 a-m	2,104 q	49,3 a-n	79,54 a-m	7052 a-q
C2 (check)	13,82 b-n	40,20 b-s	31,26 c-u	277,6 a-m	2,898 b-q	42,7 n-x	81,40 a-j	8556 a-ı
MT39	12,99 e-n	33,55 j-t	29,16 f-u	273,1 a-m	2,594 e-q	52,0 a-j	81,79 a-ı	5202 n-q

MT40	14,64 a-j	43,30 b-r	33,61 a-n	307,6 a-l	2,964 b-p	50,1 a-l	83,01 ab	8745 a-ı
MT41	15,34 abc	52,30 a-f	36,31abc	334,6 a-e	3,454 abc	55,5 ab	82,47 a-e	6085 g-q
MT42	14,34 a-m	45,30 a-o	32,91 b-q	298,6 a-m	3,174 b-l	44,8 k-v	82,67 abc	8765 a-ı
MT43	14,14 b-n	44,55 a-q	32,91 b-q	296,6 a-m	3,144 b-n	55,9 a	82,15 a-g	7515 a-o
MT44	13,44 c-n	37,30 f-t	30,71 c-u	275,6 a-m	2,754 b-q	43,4 m-w	82,28 a-g	8175 a-j
MT45	12,94 e-n	35,30 ı-t	28,51 j-u	263,6 b-m	2,694 c-q	45,3 h-v	81,88 a-h	5215 m-q
MT46	13,64 c-n	38,30 d-t	30,31 d-u	278,6 a-m	2,794 b-q	52,1 a-j	81,25 a-k	6055 g-q
MT47	13,14 d-n	36,30 h-t	28,91 g-u	267,6 a-m	2,734 c-q	46,0 e-u	81,28 a-k	5885 h-q
MT48	13,94 b-n	42,30 b-s	31,71 b-u	286,6 a-m	3,034 b-p	45,4 h-v	81,97 a-h	5725 j-q
MT49	13,44 c-n	37,30 f-t	29,71 e-u	266,6 a-m	2,754 b-q	53,3 a-d	79,61 a-m	6045 g-q
MT50	14,74 a-h	47,30 a-l	34,41 a-ı	304,6 a-m	3,234 b-ı	40,3 s-z	77,79 ı-m	4885 pq
MT51	14,64 a-j	47,30 a-l	34,51 a-ı	315,6 a-j	3,254 b-ı	47,0 c-s	80,17 a-l	6095 g-q
MT52	14,24 a-n	44,30 a-q	32,71 b-s	298,6 a-m	3,124 b-o	50,3 a-l	82,59 a-e	6655 c-q
MT53	15,76 ab	53,05 a-e	37,33 ab	335,1 a-d	3,389 a-e	47,1 c-s	78,10 h-m	9715 a
C3 (check)	12,90 h-n	34,20 ı-t	28,14 k-u	261,8 b-m	2,656 c-q	44,9 k-v	79,88 a-m	8362 a-ı
MT54	13,96 b-n	43,05 b-r	31,13 c-u	264,1 b-m	3,089 b-o	39,6 u-z	81,60 a-ı	6765 b-q
MT55	12,96 e-n	33,05 k-t	27,63 o-u	250,1 g-m	2,519 f-q	37,0 w-z	80,14 a-l	7225 a-q
MT56	14,46 a-l	45,05 a-o	31,83 b-u	294,1 a-m	3,119 b-o	39,9 t-z	80,36 a-l	7345 a-q
MT57	13,96 b-n	39,05 c-t	31,23 c-u	282,1 a-m	2,789 b-q	42,0 p-y	83,04 a	7695 a-n
MT58	12,76 h-n	40,05 b-t	27,03 q-u	257,1 e-m	3,139 b-o	43,9 l-v	80,80 a-k	7785 a-n
MT59	13,86 b-n	39,05 c-t	30,03 d-u	278,1 a-m	2,809 b-q	34,1 z	81,16 a-k	6475 d-q
MT60	14,46 a-l	43,05 b-r	32,43 b-t	287,1 a-m	2,979 b-p	36,7 w-z	81,02 a-k	5765 j-q
MT61	13,36 c-n	34,05 ı-t	28,83 h-u	263,1 b-m	2,519 f-q	34,2 z	77,38 klm	5725 j-q
MT62	13,96 b-n	40,05 b-t	31,73 b-u	273,1 a-m	2,859 b-q	38,9 v-z	81,30 a-j	5655 j-q
MT63	13,66 c-n	37,05 f-t	30,83 c-u	274,1 a-m	2,699 c-q	44,5 k-v	81,48 a-j	5075 opq
MT64	13,86 b-n	38,05 e-t	30,23 d-u	280,1 a-m	2,729 c-q	39,7 u-z	79,94 a-m	6065 g-q
MT65	13,66 c-n	37,05 f-t	26,93stu	263,1 b-m	2,699 c-q	52,0 a-j	82,24 a-g	6055 g-q
C 4 (check)	14,44 a-l	45,00 a-o	33,36 b-o	311,4 a-j	3,104 b-o	47,0 c-s	81,11 a-k	6836 b-q
Check Mean	13,765	40,30	31,11	281,1	2,914	42,9	80,69	7457

The identical letters indicate statistical groups of identical values with a 95.0% confidence level by the Student-Newman-Keul Test (SNKT)

Alveograph Energy (AE) (W):

Due to the importance of wheat quality in determining the final product properties, it is inevitable to evaluate the physicochemical properties of wheat. For this purpose, one of the tests to determine the bread baking quality of wheat genotypes is the alveograph test. Energy, resistance/elasticity rate, and swelling index were evaluated as alveograph properties. The Alveograph energy values are classified as <50 10^{-4} joule very weak, 50-100 10^{-4} joule weak, 100-200 10^{-4} joule medium, 200-300 10^{-4} joule medium strong, 300-400 10^{-4} joule strong and >400 10^{-4} joule very strong (Williams et al.,1988). In wheat breeding, the alveograph energy of the genotype to be selected should be as high as possible (even over 300 10^{-4} joule) in terms of strong gluten structure and good bread-making properties. The AE values of sixty-five advanced bread wheat mutant lines ranged between 227.3 and 343.3 10^{-4} joule and between 261.8 and 311.4$10^{-4}$ joule in check genotypes (Table 2). According to the critical classification values recommended according to the AE values, 50 lines (76.9%) of the mutants were in the medium-strong group, while 15 (23.1%) were in the strong group. However, only eight of these 15 lines (MT4, MT5, MT8, MT32, MT35, MT41, MT51 and MT53) gave the highest AE values compared to the control genotypes (Table 2). When compared with the AE averages of maternal genotypes; although the AE values of the Kate A-I mutant lines increased between 1.80% and 21.87%, decreases in AE were observed in general for the lines developed from the other mother genotypes. Along with these eight lines, the 7 lines (lines MT11, MT24, MT25, MT14, MT28, MT40 and MT50) with energy values above 300$10^{-4}$ joule were also determined to have strong gluten structure and good bread-making properties.Our results are supported by the findings of Mangova andRachovska (2004) who reported that 5 (29.4%) of the fifteenhybrid radiation mutant lines and two chemical mutant lines had higher energy for dough deformation than the standard varieties and other mutant lines.

Quality Index (QI):

The ratio between the Zeleny sedimentation value and the protein content (ZSV/GPC) is called the quality index and is accepted as an indicator of the protein amount and quality in the grain (Halverson andZeleny, 1988). It has been stated that in addition to the sedimentation values, which are accepted as a simple, fast and reliable method for determining the flour quality, the QI can be used as an effective criterion in quality selection in the wheat breeding programs (Boyadjieva andMangova, 2007).Considering this character, the means of the QIfor the 65 advanced bread wheat mutant lines ranged from 2.104 to 4.196, while the check genotypes ranged from 2.656 to 3.104 (Table2). When compared with the QIaverages of the parent genotypes; while overall decreases were observed in the lines developed from the IBWSN4 and Avustralya genotypes, the mean increase in the majority of the Bezostaja1 and Kate A-I mutant lines was between 1.80% and 21.87%. Among them, 18 mutant lines (MT6, MT4, MT2, MT5, MT8, MT11, MT23, MT24, MT25, MT26, MT14, MT41, MT42, MT43, MT50, MT51, MT52 and MT53) were a QI means than the Avustralya check genotype, which gave the highest mean. Evaluation of the QI together with the GPC and ZSV may be more accurate, and from this point of view, lines with a protein above 14%, above 50 mLZSV and with a high QI can be defined as very high quality, this priority makes them suitable genetically material to be included in the breeding programs for high quality (Boyadjieva andMangova, 2007).

Thousand Grain Weight (TGW) (g):

Thousand grain weight (g) or seed index, which is an important yield factor that directly affects grain yield, is one of the important physical quality factors that is an indicator of grain size and determines grain quality, and it can be used confidently for quality predictions in breeding studies (Çölkesen,1993;Atlı, 1999).In our study, the TGW means ranged from 34.1 to 55.9 g for the 65 advanced bread wheat mutant lines ranged from 36.9 to 47.0 g for the check genotypes. Considering the TGW averages of mother genotypes; the mean increase in the majority of Bezostaja1, IBWSN4 and Kate A-I mutant lines was between 0.88% and 30.90%, while overall decreases were observed in lines developed from Avustralya genotypes. Among the bread wheat mutant lines, 30 lines were a higher TGW than the check genotype. These results show that a wide variation can be achieved with the application of mutagen for TGW. Fifteen mutant lines (MT43, MT41, MT5, MT49, MT21, MT46, MT65, MT39, MT8, MT7, MT20, MT29, MT52, MT40 and MT19) draw attention with an average of TGW above 50 g (Table 2). Our results are similar to the results of Singh andBalyan (2009),Sial et al. (2010)who illustrated mutant lines with larger grains than the parents can be obtained as a result of gamma irradiation, while it is contradictory to the findings by Öztürk et al. (2020) who the mutant lines have a lower thousand-grain weight than their parents.

Test weight (TW) (kg hl^{-1}):

Test weight, defined as the weight of 100 litres of grain in kg; The fullness, density, size, shape and homogeneity of the grain are the most important features that determine the test weight (Yürür,1994), andit changes depending on the variety, planting season, soil characteristics, foreign matter and moisture content (Kün, 1996).TW is an indicator of wheat quality and flour yield (Gooding and Davies, 1997; Manley et al., 2009).The importance of TW, especially for growers, has been reported by Schuler et al. (1995) because of its impact on market grade. Thus, it can be said that it would be beneficial to consider the TW, an important physical quality criterion, in the selection of commercial cultivar candidates. Considering the TW averages, it is seen that mutant lines gave averages varying between 75.94 and 83.04 kg hl^{-1}, while those of standard cultivars ranged between 79.88 and 81.40 kg hl^{-1}(Table 2).Based on TW averages of source genotypes; overall decreases were observed in lines developed from IBWSN4 and except for 2 lines of the Avustralya genotypes, while the average increase in most Bezostaja1 and Kate A-I mutant lines was between 0.15% and 3.77%.Among the tested mutant lines, 11 lines (MT26, MT23, MT13, MT8, MT6, MT3, MT7, MT54, MT57, MT63 and MT65) was found to have a higher TW than the check IBWSN4 genotype, giving the highest mean and other parents. It has been reported that the TW used in the commercial classification of bread wheat should be between 74-78 kg hl^{-1} (Anonymous, 1978), wheat with values above 80 kg hl^{-1} are evaluated as extra-extra (Yürür, 1994) and genotypes exceeding 82 kg hl^{-1} value are considered very good. (Diepenbrock et al., 2005). Test weight varies according to the shape, density, size and homogeneity of the wheat grains (Ünal, 1991). It is seen that our 24 lines are compatible with TW values between 75 and 80 kg hl^{-1}, 30 lines can be evaluated as extra with TW values between 80 and 82 kg hl^{-1} and 11 lines can be evaluated very well with TW values above 82 kg hl^{-1} according to this commercial classification. Our findings are relatively similar to the results of a limited number of previous studies showing that mutagen treatments cause significant changes in TW in wheat (Öztürk et al., 2020).

Grain yield (GY) (kg ha^{-1}):

The main purpose of plant improvement is to increase grain yield obtained from the unit area. Grain yield is polygenic and is highly influenced by cultivar, environment and cultivar x environment interactions. The average performance of grain yield (kg ha^{-1}) of all genotypes is depicted in (Table 2). In the study, the grain yield of advanced bread wheat mutant lines ranged from 4712 to 9715 kg ha^{-1}, while the grain yield of check genotypes ranged from 6074 to 8556 kg ha^{-1}(Table 2). Based on GY averages of source genotypes; overall decreases were observed except for 6 of the lines developed from IBWSN4, 3 of the lines from Kate A-I, and 4 of the lines from Avustralya, while average increases in most Bezostaja1 mutant lines ranged from approximately 0.87% to 20.36%.Based on TW averages of source genotypes; overall decreases were observed in lines developed from IBWSN4 and except for 2 lines of the Avustralya genotypes, while the average increase in most Bezostaja1 and Kate A-I mutant lines was between 0.15% and 3.77%.Considering the other characteristics examined, it is seen that there is a higher variation in grain yield between mutant genotypes obtained by gamma irradiation. Considering the relevant results, the GY potential of the 10 mutant lines appears to be well above the expected average wheat yield (8400 kg ha^{-1}) highlighted by Gençtan (2015) under the conditions of the Thrace Region located in the north-western part of Turkey.Among them, 6 mutant lines (MT53, MT14, MT20, MT33, MT35 and MT19) draw attention with an average of GY above 9000 kg ha^{-1}. However, MT1, MT11, MT12, MT13, MT16, MT28, MT29, MT32, MT43, MT31, MT55, MT56, MT57 and MT58 were also the mutant lines with the closest grain yields to the regional potential average. Ayub et al. (1989) stated that the effect of different doses of gamma rays irradiation on the grain yield of wheat varieties responded differently in different varieties. Our results are in confirmation with those of Öztürk et al. (2020) who explained that 33% of the mutant lines have more grain yield than the parents and check genotypes. As a result, it can be said that it would be appropriate to take these 9 mutant lines into the pre-registration yield trials in terms of grain yield.

Conclusion:-

As a result of the study, 15 lines for GPC, 16 lines for ZSV, 13 lines for WGC, 15 lines for AE, 18 lines for QI, 30 lines for TGW, 11 lines for TW, and 10 lines for GY were found to outperform the main genotypes. Observation of increases for generally examined traits in mutant lines developed from well-adapted commercial parent cultivars indicated that it would be more appropriate to use these cultivars as source material in mutation breeding. On the results of the quality traits, MT8, MT4, MT5, MT6, MT23, MT24, MT25, MT41, MT50 and MT51 mutant lines were superior quality for protein quantity and quality, and 10 mutant lines may prove useful as a parent for quality improvement in a wheat breeding programme. Mutant lines with the highest grain yield performance were MT53, MT14, MT20, MT33, MT35 and MT19. By evaluating the research results together, it was determined that the mutant lines MT53, MT14, MT35 and MT11 had the best grain yield and quality performances. The mutant lines (MT53, MT14, MT33, MT35, MT20, MT19 and MT11) were selected for pre-registration yield trials. Population growth and improvements in living conditions require increases in grain protein content and quality along with wheat grain yield. As a result of the research, the fact that both high quality and yield new cultivar candidates with high agricultural value have been obtained shows that mutation breedingcan make a significant contribution to achieving this goal.

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