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A Review on Genetic Improvement Strategies for Increasing Wheat yield

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An increase in productivity is always one of the main goals of any crop breeding program including wheat. Even though there was a series of breakthroughs the main breeding goals in most international programs remain similar since a long time ago: increasing grain yield potential, resistance to disease, grain quality, and drought tolerance. Increase in grain yield potential is the major goal of almost all wheat breeding programs. The major impacts are related to the development of new strategies to increase the genetic grain yield potential of the varieties. Wheat breeders have been very successful in improving the crop. Conventional breeding methods mainly used to improve self-pollinating crops including wheat are Pedigree, mass selection, etc, but development of hybrids, new plant types and mutation breeding are added to the breeder's portfolio. Breeders have been taking advantage of biotechnology tools in order to accelerate wheat improvement programs as the main additional tool to conventional wheat breeding strategies; however, many programs are still struggling on how to integrate them into the breeding programs especially in developing countries. Generally to improve wheat production and productivity for the changing climate and the increasing world population as well as the increasing demands, it is advisable to use several genetic improvement strategies rather than a single method.

Key words*:* Grain yield, genetic improvement, Wheat

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INTRODUCTION

Bread wheat (*Triticum aestivum* L.) is a self-pollinated annual plant belongs to the family *Poaceae*, tribe *Triticeae* and genus *Triticum* (*Belderok et al., 2000)*. The genus *Triticum* is represented by seven species, out of which the major ones are *Triticum durum* and *Triticum Aestivum*. Previous studies indicated that cultivation of wheat occurred about 10,000 years ago, which is considered as part of the 'Neolithic Revolution . These earliest cultivated forms were diploid (genome AA) einkorn and tetraploid (genome AABB) emmer wheat and their genetic relationships indicate that they originated from the south-eastern part of Turkey (Dubcovsky and Dvorak, 2007).

Wheat is one of the most important export and strategic cereal crop in the world and in Ethiopia in terms of production and utilization (Ranjana and Kumar, 2013). Wheat grain is valued for traditional fermented thin bread ("injera"), regular bread ("dabo"), and local beer ("tella")

(Tsegaye and Berg, 2007). It accounts for 20% of nutritional sources of the people around the world and provides nearly 55% of carbohydrates, 20% of the daily protein and 21% calories for about 40% of the global population (Khan and Naqvi, 2011; Khabiri *et al*., 2012).

Wheat is produced under a wide range of climatic conditions and geographical areas, and due to its high adaptability to diverse climactic and other environmental conditions, its distribution range is more than any other plant species. It is grown from temperate, irrigated to dry and high-rain-fall areas and from warm, humid to dry cold environments (Kamali, 2008).

Global wheat production in 2019/20 was 768.07million metric tons (mMT) with average yield (3.51 tone/ha) on 218.78 million hectares of land (USDA, 2019). However, Africa produced more than 25 million tons (MT) on 10 million hectares (Mha) of land. Sub-Sahara Africa (SSA) produced a total of 7.5 million tons (MT) on a total area of 2.9 million hectares (Mha) accounting for 40 and 1.4 per cent of the wheat production in Africa and at global levels, respectively (FAO, 2017). Whereas, in Ethiopia wheat is produced on 1.7 million hectares of land and has the production of 4.64 million tons with average productivity of 2.74 t ha^{-1} (CSA, 2018).

The increasing demand for wheat at global level due to the increasing world population as well as increasing urbanization, changing in food habit and the challenges facing wheat production such as climate change, increased cost of inputs, increased intensity of abiotic (drought, heat) and biotic (diseases and pests) stresses, on the other hand, make the wheat demand-supply chain very volatile and at times lead to social turbulence. It is expected that demand for wheat in developing countries will increase by 60 per cent in the year 2050 (Rosegrant and Agcaoili, 2010). The same author also reported that global wheat grain production must increase 2% annually to meet the requirement of consistently increasing world population (around 9-10 billion) till 2050. The significant increases in yield are unlikely to be attained through only the traditional, or even the newly developed marker-assisted breeding methods. Most wheat improvement strategies are focusing on adaptation studies but new methods and approaches must be found to integrate to attain the dramatic yields that would be required to meet future demands and the substantial additional losses attributed to biotic factors(diseases and insect pests) and abiotic factors (drought, salinity, etc.) (Oerke *et al.,* 1994).

Therefore, this currently designed review will focus on various genetic improvement strategies or approaches to boost wheat production and productivity:

- Conventional breeding and hybridization
- The new Plant type (ideotype) breeding
- Hybrid breeding
- Mutation breeding
- Integration of new biotechnologies in Wheat breeding programs
- Molecular Marker Assisted Breeding

LITERATURE REVIEW

Breeding methods to improve wheat production and productivity

Conventional breeding and hybridization

This is the time tested strategy for selecting crop cultivars with higher yield potential. It has two phases. The first phase involves the creation of variability through hybridization among diverse parents. In the second phase desirable individuals are selected on the basis of field observations and yield trials. It was reported that for thousands of years improvement of wheat was achieved by careful selection of the best grain from well adapted plants and desirable characters such as ease of harvesting, shorter growing seasons, better milling and baking qualities, improved disease resistance and higher yields are combined by crossing selected wheat varieties but takes about ten to twelve years of testing at a cost of around 0.5 mio USD for a new variety to be released (NAMA, 2005).

The New Plant Type (Ideotype) Breeding

The new plant type or ideotype breeding is an architectural modification aimed to achieve increases in yield potential of wheat and other cereals. Studies were conducted by researchers of major crops to determine best plant type or ideotype that can efficiently utilize resources and convert them into maximum obtainable yield. As reported by Berry *et al.* (2007), the best ideotype of wheat plant is the one with the yield potential of 8 t/ha and key parameters required to develop this type of wheat are shorter plant height, wider root plate, and appropriate stem strength especially at the bottom internodes. Additionally, Tendon and Jain (2004) reported that thick stems, fewer tillers, large heads, higher number of grains, and high harvest index as the best model plant designed to achieve high yield in wheat.

Some of the traits with potential application to the improvement of wheat crops cultivated in Africa include:

Plant architecture and anatomy: Architectural changes in plant include alteration in branching Pattern and reduction in plant height. Semi-dwarf wheat varieties developed during the Green Revolution tremendously increased the productivity of these crops. Plants with erect leaf phenotype or narrow leaf angle are efficient in capturing the light and hence boosting productivity. According to Rasmussan *et al*. (1991), wheat and barley plants with large stems, leaves, and heads produce superior yield.

Photosynthetic efficiency: Several researchers such as Reynolds *et al*., (2009), reported in wheat, improving photosynthesis by exploiting natural variation in Rubisco's catalytic rate or adopting C4 metabolism raised the yield potential by at least 50% through genetic improvement of radiation use efficiency (RUE). Parry *et al*. (2011) reported that past increases in yield potential of wheat have largely resulted from improvements in harvest index at a certain level but an opportunity exists for increasing productive biomass and harvestable grain through improving photosynthetic capacity of wheat. Foulkes *et al.* (2011) also reported that spike growth, spike fertility, grain size, and lodging resistance are other approaches that can improve photosynthetic capacity of wheat.

Yield components: Since yield is affected by multiple traits, breeding programs have focused mainly on improving individual traits known as yield components or yield-related traits such as panicle yield, number of tillers, seed weight, and others.

Stress tolerance and water-use efficiency: Severe climatic and soil conditions adversely affect productivity of wheat and other crops, many breeding programs are geared towards developing crops that are resilient to some of these environmental calamities. Blum *et al*., (2009) reported breeding for effective use of water as the best strategy towards mitigating the effects of moisture scarcity and to develop drought tolerant crops. Araus *et al*. (2002) reported WUE (water use efficiency) can be modified through an increase in photosynthetic capacity in addition to decrease in stomata conductance.

Hybrid Breeding in Wheat

Improvements in wheat yields will be critical in ensuring global food security for the ever increasing world population around (9-10 billion). So to meet this goal, one of the most promising options is to capture the yield benefits from heterosis in a hybrid wheat programme. Although, the ability to exploit heterosis (hybrid vigor) in wheat has historically been difficult due to the strong inbreeding nature of wheat, a factor governed primarily by floral development, architecture and lack of practical fertility control systems. However, recent estimates of yield improvements associated with heterosis in wheat range from 3.5 to 15% (Longin *et al*., 2012).

Heterosis and hybrid performance of complex agronomic traits such as grain yield is very probably influenced by many loci. Genomic selection has been suggested to predict the phenotype for traits that are controlled by multiple genes with small effects. According to Zhao *et al.,* (2013) genomic selection has been used successfully to predict hybrid performance in wheat. It is therefore time that 'hybrid wheat' is reassessed, especially in terms of modifying floral architecture to facilitate hybrid seed production based on new strategies, technologies and knowledge.

Mutation Breeding

Mutation breeding is the deliberate induction and development of mutant lines for crop improvement (Freisleben and Lein, 1942). The term has also been used in a wider sense to include the exploitation of natural as well as spontaneous mutants, and in the development of any variety possessing a known mutation from whatever source. It is relatively a quicker method for improvement of crops (Ilirjana, 2007). Ram *et al*., (2003) and Morten *et al*., (2006) reported that hundreds of useful mutants have been induced for various plant characteristics in variety of crops including wheat through treatment with physical and chemical mutagens. It was also reported that more than 1800 cultivars obtained either as direct mutants or derived from their crosses have been released worldwide in 50 countries (Ahloowalia, 2001). These induced mutation help to develop many agronomical important traits such as shorter growing period, suitable for rotation, increased tolerance to or resistance to abiotic and biotic stresses use in major crops such as wheat, rice, barley, cotton, peanuts and beans (Ahloowalia, 2001; Maluszynski *et al*., 2002). Kharkwal and Shu (2009) also reported that breeding programmes based on efficient mutation techniques have been widely used by plant breeders and many of our food crops are derived either directly or indirectly from such programmes.

Integration of New Biotechnologies in Wheat Breeding Programs

▪ Recombinant DNA Technology/Genetic Engineering

Although conventional breeding programmes have led to continuous improvements in some of the economically important traits, emergence of new threats and climatic challenges calls for a faster action towards development of varieties resistant to emerging pests and diseases, and abiotic stresses. In the advent of rDNA technique and transformation methods, a new way of incorporating defined genetic changes into plants is quite possible.

The continuous development of agro bacterium-based gene transfer systems and biolistics methods for improving its efficiency and applicability to many crops is rapidly replacing other methods for generation of transgenic plants, but between these two methods agro bacterium method is more robust compared to the biolistics approach. Nevertheless, tissue culture techniques have played a major role in transferring gene of interest and transgenic plant recovery. Davis and Reznikov (1992) documented in their work the classical example which has been used in a range of protoplast, microspore, tissue and organ culture protocols. Despite several disputes, field trials of transgenic plants have recently become much more common.

- ***Transgenic wheat for increased yield and Quality***

Given the socioeconomic importance of wheat, many efforts of breeding have focused on improving its yield, quality, and adaptability to biotic and abiotic stresses. Generally, wheat yield and quality can be affected by various environmental constraints such as high temperature, drought, or the combination of these two (Wardlaw *et al.,* 2002; Stratonovitch and Semenov, 2015). Most previous studies indicated that elevated temperature during wheat anthesis and grain filling stages significantly reduces grain yield (Bhullar and Jenner 1986a; Keeling *et al., 1993;* Farooq *et al., 2011;* Prasad and Djanaguiraman, 2014). It was also reported that short-term heat stress could cause 11–23% reduction in grain number and 10–26% reduction in individual grain sizes in wheat (Talukder *et al., 2013).* Therefore, improving the heat tolerance in wheat has been considered a key goal that would result in yield stability (Kuchel *et al., 2007).*

- ***Transgenic wheat for increased resistances to insects and diseases***

Resistance breeding is a continuing and difficult process as resistance in most cases appears to be under polygenic control, and even when resistant cultivars are developed, they do not provide long-term relief due to ever-evolving or mutating pathogens (Friesen *et al.,* 2006).

- ***Transgenic wheat for herbicide and insecticide resistance***

Several researchers developed resistance wheat for various weeds and insect pests. Gopalakrishnan *et al.* (2000) has established highly efficient micro projectile bombardment method of wheat transformation in CPAN004, Sonalika and UP2338 varieties of Indian wheat and successfully transformed the bar gene to get putative transformants. Patnaik *et al*. (2006) also developed the transformation of mature embryos of T. aestivum and T. durum with 200 µM acetosyringone and 2-3 days of co-cultivation with LBA4404 agro strain and putative transformants were obtained for bar gene (herbicide resistance) and proteinase inhibitor (pin 2) gene for insect resistance in wheat.

- ***Transgenic wheat for abiotic stress resistance:***

Several researches developed wheat varieties for abiotic stress resistance using different gene transformation methods. Kasirajan *et al*.(2014) transformed the AtCBF3 gene into HDR77-A wheat variety with particle bombardment method and validated the putative T1 plants under moisture stress conditions, which showed 8% yield advantage over wild type plants under stress. Furthermore, Patnaik and Khurana (2003) showed particle bombardment method of gene transfer in T. aestivum (CPAN1676) and T. Durum (PDW215) with mature embryos. The transgenic with HVA1 gene were developed and transformation was confirmed under controlled conditions in to plants.

Molecular Marker Assisted Breeding

Application of markers for breeding disease resistant varieties is especially interesting when breeding for resistance traits which are difficult or expensive to assess phenotypically. A prominent example is the selection for resistance to nematodes. In wheat there is extensive use of DNA markers for cereal cyst nematode (Heterodera avenaeWoll.) resistance (Eagles *et al*., 2001). It was also reported that Ug99 is the most important disease of wheat currently in the world and the fastest way to reduce the susceptibility of important wheat cultivars and the best new germplasm is to systematically incorporate combinations of diverse resistance genes through limited or repeated backcrossing. Because most of the useful Ug99-effective genes are of alien origin, available co-segregating molecular markers can aid in their selection (Singh *et al*., 2008).

CONCLUSION

Bread wheat (*Triticum aestivum* L.) plays a major role among the few crop species being extensively grown as staple food sources. As the human population grows, new methods and approaches must be found to attain wheat cultivars with improved characteristics. The ultimate goal of crop breeding is to develop varieties with high yield potential, resistance to biotic and abiotic factors. In wheat breeding, the most important qualities sought by breeders have been high yield potential; resistance to major diseases and insects; and improved grain and eating quality. Various strategies to increase the yield potential include: conventional hybridization, heterosis breeding, ideotype breeding, Mutation breeding, genetic engineering and molecular marker assisted breeding. Conventional breeding is still a widely used strategy for developing crop varieties with a higher yield potential. Modifying the plant architecture is also an important breeding strategy to achieve increased wheat yield potential. Mutation breeding is also very useful in situations where only one or two simple changes in well adapted local cultivars are needed so as to include gene complexes for tolerance to biotic and abiotic stresses, grain quality etc. The integration of molecular biology, genomic research, transgenic breeding and molecular marker applications with conventional plant breeding practices has created the foundation for molecular plant breeding and certainly accelerated wheat improvement programs across the world. Recombinant DNA technology has resulted in production of transgenic wheat with new genetic traits and for resistance to biotic and abiotic stresses. Marker-assisted selection (MAS) has become integral component of germplasm improvement. A large number of genes for various traits have been tagged with molecular markers to apply MAS for trait improvement. Map-based cloning has resulted in isolation of several genes for resistance to biotic and abiotic stresses as well as yield related traits. This has opened the possibility of applying MAS for yield enhancement in wheat. Generally, it can be concluded that use of multiple genetic improvement strategies could be the best way to improve wheat production and productivity.

FUTURE PROSPECTS

Wheat production will have to be doubled to meet increasing world demands and future needs. This increase must be brought about by using different genetic improvement strategies in order to reduce losses caused by biotic and abiotic stresses. However, the increasing new race of diseases and insect pests as well as the changing climate is a challenging problem for wheat production and productivity in Ethiopia as well as in the world. Besides conventional breeding strategies, focus must be given on integration of new technology in wheat breading program.

REFERENCES

Ahloowalia, B.S. and M. Maluszynski, 2001. Induced mutations - A new paradigm in plant. Euphytica, 118 (2): 167-173.

Araus, J.L. Slafer, G.A. Reynolds, M.P. Royo, C., 2002. Plant breeding and drought in C3 cereals: What should we breed for? Ann. Bot., 89, 925–940.

Belderok B, Mesdag H, Donner, D.A., 2000. Bread-Making Quality of Wheat. Springer. p.3.

Berry, P.M. Sylvester-Bradley, Berry S., 2007. Ideotype designs for lodging-resistant wheat. Euphytica, 154,165–179.

Bhullar, S., Jenner, C., 1986a. Effects of a brief episode of elevated temperature on grain filling in wheat ears cultured on solutions of sucrose. *Aust. J. Plant Physiol* 13:617–626

Blum, A., 2009. Effective use of water (EUW) and not water-use efficiency (WUE) is the target of crop yield improvement under drought stress. Field Crops Res. 112, 119–123.

CSA (Central Statistical Agency), 2018. Report on Area and Production of Major Crops (Private Peasant Holdings, Meher Season). Statistical Bulletin No.586. Centeral Statistics Authority of Ethiopia, Addis Ababa

Davis, J. and Reznikov,W.S., 1992. Milestone in Biotechnology: Classic Papers on Genetic Engineering. Boston: Butterworth-Heinemann.

Dubčovský, J. Dvořák, J., 2007. Genome plasticity a key factor in the success of polyploid wheat under domestication. Science, 316, 1862-1866

Eagles, H. A. Bariana, H. S. Ogbonnaya, F. C. Rebetzke, G. J. Hollamby, G. J.Henry, R. J. Henschke, P. H. & Carter, M., 2001. Implementation of Markers in Australian Wheat Breeding. *Australian Journal of Agricultural Research* 5 2:1349-1356.

FAO (Food and Agricultural Organization), 2017. Crop Pr ospects and Food Situation. Quarterly Global Report. March 2018.

Farooq, M., Bramley, H, Palta, J.A. Siddique, K.H.M., 2011. Heat stress in wheat during reproductive and grain-filling phases. Crit Rev Plant Sci 30:491–507.

Foulkes, M.J. Foulkes, M.J. Slafer, G.A. Davies, W.J. Berry, P.M. Sylvester-Bradley, R. Martre, P.Calderini, D.F. Griffiths, S.Reynolds, M.P., 2011. Raising yield potential of wheat. III. Optimizing partitioning to grain while maintaining lodging resistance. *J. Exp. Bot*. 62, 469–486.

Freisleben, R. and Lein, A. 1942. Uber die Auffindung einer mehltauresistenten mutante nach Roentgenbestrahlung einer anfaelligen reinen Linnie von Sommergerste. Naturwissenschafen. 30: 608.

Friesen, T.L.Stukenbrock, E.H. Liu, Z. Meinhardt, S. Ling, H. Faris, J.D.Rasmussen, J.B. Solomon, P.S. McDonalds, B.A.Oliver, R.P., 2006. Emergence of a new disease as a result of interspecific virulence transfer. Nat. Genet., 38, 953-956.

Gopalakrishnan, S, G.K. Garg, D.T .Singh and N.K .Singh. 2000. Herbicide-tolerant transgenic plants in high yielding commercial wheat cultivars obtained by micro projectile bombardment and selection on Basta. Current Science 79: 1094-1100.

Ilirjana, S., Y. Ariana and D. Andon, 2007. Induced Mutations for Improving Production on Bread and Durum Wheat. Sixth International Conference of the Balkan Physical Union.

Kamali, J. M., 2008. Review on wheat status in the past, present and future. Key papers for 10th conference on sciences of breeding in Iran: pp.23-45.

Kasirajan L, K Boomiraj and K. C. Bansal. 2014.

Optimization of genetic transformation protocol mediated by biolistic method in some elite genotypes of wheat (*Triticum aestivum* L.). *African Journal of Biotechnology,* 12(6): 531-538.

Keeling PL, Bacon PJ, Holt DC., 1993. Elevated temperature reduces starch deposition in wheat endosperm by reducing the activity of soluble starch synthase. Planta, 191:342–348.

Khabiri, E., Imani, A.A. and Shahbazi, H., 2012. Studying the grain yield and yield components in advanced rain fed wheat genotypes. Scholars Research Library. Annals of Biological Research, 3 (12):5647-5650

Khan, N. and Naqvi, F.N., 2011. Heritability of Morphological Traits in Bread Wheat Advanced Lines Under Irrigated and Non-Irrigated Conditions. Asian Journal of Agricultural Sciences, 3(3): 215-222

Kharkwal, M.C. and Shu, Q.Y., 2009. Role of induced mutations in world food security. pp. 33-38. In: Q.Y. Shu (ed.) Induced Mutations in the Genomic Era. Food and Agriculture Organization of the United Nations, Rome.

Kuchel H, Williams K, Langridge P, Eagles, H.A, Jefferies, S.P., 2007. Genetic dissection of grain yield in bread wheat. II. QTL-by-environment interaction. Theor Appl Genet 115:1015–1027.

Longin, C.F.H, Mühleisen J, Maurer HP, Zhang H, Gowda M, Reif JC., 2012. Hybrid breeding in autogamous cereals. Theoretical and Applied Genetics 125, 1087–10

Maluszynski, M. and K.J. Kasha (Eds.), 2002. Mutations, in vitro and Molecular Techniques for Environmentally Sustainable Crop Improvement. Kluwer Academic Publishers, Dordrecht/Boston/London.ISBN 1-4020-0602-0.

Morten, L., C. Feng, X. Xianchun, W. Manilal, J.P. Roberto, R. Trethowan and Z. He, 2006.Puroindoline grain hardness alleles in CIMMYT bread wheat germplasm. *J. Cereal Sci*., 44(1): 86-92.

NAMA (North American Millers' Association), accessed J une 2005,http://www.namamillers.org.

Oerke, E.-C., Dehne, H.-W., Schonbeck, F., Weber, A., 1994. Crop production and crop protection. Elsevier, Amsterdam.

Parry, M.A.J.; Reynolds, M.; Salvucci, M.E.; Raines, C.; Andralojc, P.J.; Zhu, X.G.; Price, G.D.; Condon, A.G.;Furbank, R.T., 2011. Raising yield potential of wheat. II. Increasing photosynthetic capacity and efficiency. Exp. Bot., 62, 453–467.

Patnaik D and P. Khurana. 2003. Genetic transformation of Indian bread (*T. aestivum*) and pasta (*T. durum*) wheat by particle bombardment of mature embryo- derived calli. BMC Plant Biology, 3: 5

Patnaik D, D Vishnudasan and P Khurana. 2006. Agrobacterium-mediated transformation of mature embryos of Triticum aestivum and Triticum durum. Current Science 91: 307- 317.

Prasad PVV, Djanaguiraman M., 2014. Response of floret fertility and individual grain weight of wheat to high temperature stress: sensitive stages and thresholds for temperature and duration. Funct Plant Biol 41:1261-1269

Ram Din, M.M. Khan, M. Qasim, S. Jehan and M.M. Iqbal Khan, 2003. Induced mutation studies in three wheat (*Triticum aestivum* L.) varieties for some morphological and agronomical characters, *Asian J. Plant Sci*., 2(17-24): 1179-1182.

Ranjana and Suresh Kumar, 2013. Study of genetic variability and heritability over extended dates of sowing in bread wheat (*Triticum aestivum* L.). Research in Plant Biology, 3(1): 33-36

Rasmusson, D.C., 1991. A Plant Breeders Experience with Ideotype Breeding. Field Crops Res. 26, 191–200.

Reynolds, M.; Foulkes, M.J.; Slafer, G.A.; Berry, P.; Parry, M.A.; Snape, J.W.; Angus, W.J., 2009. Raising yield potential in wheat. *J. Exp. Bot*. 60, 1899–1918.

Rosegrant, M.W. and Agcaoili, M., 2010. Global Food Demand, Supply, and Price Prospects, International Food Policy Research Institute, Washington, DC

Singh RP, Hodson DP, Huerta-Espino J, Jin Y, Njau P., 2008. Will stem rust destroy the world's wheat crop? Adv. Agron.98:271–309

Stratonovitch P, Semenov MA. , 2015. Heat tolerance around flowering in wheat identified as a key trait for increased yield potential in Europe under climate change. *J Exp Bot* 66:3599–36-09.

Talukder, ASMHM, McDonald GK, Gill, G.S., 2013. Effect of short-term heat stress prior to flowering and at early grain set on the utilization of water-soluble carbohydrate by wheat genotypes. Field Crops Res 147:1-11.

Tandon, J.P.; Jain, H.K., 2004. Plant ideotype: The concept and application. In Plant Breeding: Mendelian to Molecular Approaches; Jain, H.K., Kharkwal, M.C., Eds.; Narosa Publishing House: New Delhi, India, pp. 585–600.

Tsegaye, B. and Berg, T., 2007. Utilization of durum wheat landraces in East Shewa, central Ethiopia: Are home uses an incentive for on-farm conservation? Agriculture and Human Values. 24, 219- 230

USDA., 2019. United States Department of Agriculture Office of Global Analysis .World Agricultural Production. Available at: https://ipad.fas.usda.gov/ (accessed August 2019). Washington DC, USA. P36.

Wardlaw IF, Blumenthal C, Larroque O, Wrigley CW., 2002. Contrasting effects of chronic heat stress and heat shock on kernel weight and flour quality in wheat. Funct Plant Biol 29:25-34.

Zhao Y, Zeng J, Fernando R, Reif J.C., 2013. Genomic prediction of hybrid wheat performance. Crop Science 53, 802–810.