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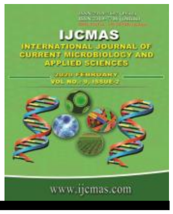

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Wheat Heat Tolerance: Mechanism, Impact and Quantitative Trait Loci Associated with Heat Tolerance

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ABSTRACT

Wheat (*Triticum aestivum* L.) is one of the important cereal crops. It has the top first rank in among cereals because of which it has most significant contribution to the worldwide. Now day’s high temperature is continuing raising that affected to wheat crop. This temperature is risen by human activities and some other activities. Heat stress is an abiotic phenomenon that resulting the losses in yield. High temperature alters the primary phenomena such as growth and development and also affect to the physiological responses and biochemical aspects. So we need to develop heat tolerance variety that can give good yield performance during heat stress. This may be achieved by the knowledge of whole plant mechanism such as mechanism of heat tolerance with plants, morphological responses, anatomical responses, physiological responses and expression of gene. Now days most of the tool to be adopted is molecular marker to know the idea about mechanism of heat stress. Molecular marker system reveals idea about which one gene/ QTLs associated with heat tolerance.

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Introduction

Wheat (*Triticum aestivum* L.) is one of the most important Rabi cereals crop in all over the world. It is a thermo stable crop that is cultivated on latitudinal distribution (Sahu *et al.*, 2002). Wheat is consumed by the human in all tropical and subtropical areas in developing as well as developed nations. It grows mainly 15-18^{0}C optimum temperature (Chaudhary and wardlaw, 1978). But above temperature from particular temperature, it suffers the chronic heat tolerance during reproductive phase and vegetative growth. Main causes of high temperature are the global warming (Iba, 2002). Heat stress affected to the production of wheat in arid and semi-arid areas. So to consider these problems we need to develop heat tolerance variety for public domain. Genetic diversity for wheat heat tolerance has been well created (Al-Khatib and Paulsen, 1990; Reynolds *et al.*, 2009). If temperature rose from optimal temperature then this temperature reduces to wheat yield (Fokar *et al.*, 1998; Maestri *et al.*, 2002). There are many traits such as earliness, leaf rolling, leaf motif, plant height and grain filling duration has been associated with wheat heat tolerance (Blum *et al*.,1997, Fokar *et al.*, 1998; Reynolds *et al.*, 2009). There are many physiological traits associated with wheat heat resistance such as photosynthetic rate, stomata conductance and thermal stability (Al-Khatib and Paulsen, 1984; Fokar *et al*.,1998; Reynolds *et al.*, 2009). High temperature at this time is produced severe loss to wheat production over worldwide (Hays *et al.*, 2007).

Heat changes the morphological and anatomical structure of wheat plants resulting losses in yield (Stone and Nicolas, 1995). Physiological basis of wheat plants decide to select better genotype during high stress, this approach is very helpful to decide the tolerated variety. But this point should be always note that a variety gives good performance in heat tolerance, than we cannot consider that variety will give good yield performance under drought tolerance (Reynolds *et al.*, 2009). Hence there is any other method need to predict the heat resistance variety such as marker assisted breeding/ marker assisted selection (MAS/MAB). Hence need the QTLs mapping to detect QTLs that is associated with heat resistance with the help of molecular markers (Kato *et al.*, 2000). It is proved that heat stress is controlled by the quantitative nature and it is inherited from generation to generation (Blum *et al.*,1989; Yang *et al.*, 2002). To detect the QTLs for heat tolerance is being by many plant breeders in different environment breeding programmes on different population (See table).

The main objective of QTLs mapping to detect the quantitative trait associated with heat tolerance with the help of molecular marker breeding (Mohammadi *et al.*, 2008). There are many QTLs have been detected with the help molecular marker. They are described below (See table No. 01).

Mechanism of heat tolerance

When temperature is raised beyond level of threshold for a limited time, it can be reduced to yield. For higher yield, temperature should be normal range 18-22^{0}C. High temperature changed the physiological, morphological, anatomical and biochemical aspects of plants. High temperature must be change the plant anatomy in which plants can be mature in early stage (Porter, 2005). High temperature leads the injury levels of cellular that may be death of cells. Direct injuries of cells due to heat leads protein denaturation and also may be alter the mechanism of cell, if there is minimum temperature than it can be also inactive of enzymes and reduce the protein synthesis (Howarth, 2005). All these injuries leads to starvation death of cells in which these injuries directly affected to yield contribution characters (Smertenko *et al.*, 1997). Plants are affected in different ways such as high temperatures and low temperature and high soil temperatures. In addition there are many crops that are very sensitive to heat temperatures. In general heat tolerance is one phenomenon in which plant can be maintaining self-integrity to avoid the high temperatures and can be create good metabolic pathway.

Morphological response

Pre and post-harvest losses has been created by heat stress. In which there are some morphological responses involving such as sunburn on leaves, stem and branches, scorching of leaves, leaf abscission and senescence, inhibition of root, shoot growth, fruit dropping, discoloration, damage etc. thus resulting reduced in yield (Vollenweider *et al.,* 2005). And higher temperature also alters the phonological process from one to another. To enhance duration of high temperature decline the germination process or may be lost germination ultimately, this temperature inhibit the growth of emergence. Several plants have been affected by the high temperature in which significant reduction in yield, net assimilation ratio and shoot dry mass. It also affected to anthesis and reproduction stage of plants with the combination of heat stress and drought stress. For instances, both grain number and grain weight is also affected by the high temperature in wheat (Ferris *et al.,* 1998). Reproductive process also affected by the higher temperature because of which fertilization can occur or not.

Anatomical response

It is clarify that high temperature not only affected to plants morphology at cellular level but also affected to subcellular level. This phenomenon is happened as same as in drought stress environment. Hence plants reduced the cell size, closer the stomata, it also increase the stomata densities and other cellular activity and enhance the xylem vessels for shoot and root (Anon *et al.,* 2004). The most disadvantage of plants alteration the subcellular level in chloroplasts because of which significant changes in photosynthesis, for instances photosynthesis reduced by the higher temperature by changing in structural system of thylakoid (Karim *et al.,* 1997).

Physiological responses

High temperature on wheat, reduce the physiological responses such as reduce the spike length, lower no of spikelets, accelerate floral initiation, adversely affect on pollen development etc. the most critical period of grain filling is post anthesis, if at this time temperature is high can be reduce yield. Complete sterility may be developed on more than 30^0c temperature (Oven 1971, Kumar *et al.,* 2020; Saini and Aspinal 1982).

Previous study has been conducted where out length of vegetative growth having highly positive correlation association with no of spikelets per spike (Rehman *et al.,* 1997). While shorter length of vegetative growth having adverse effect and reduce the no of spikelets per spike. Higher temperature during floral initiation reduces the kernel number in plants. It is suggested that wheat yield and wheat quality could be improved to give heat shock treatment in early grain filling stage.

Molecular approach

It has been described that there are many methods to improve the heat tolerance genotype such as traditional, transgenic approach and conventional breeding approach. It is well suggested that heat tolerance is controlled by the multigenic trait that involve in gene expression at different level of stage in different tissue (Bohnert *et al.,* 2006).

Thus to know about the heat tolerance gene, we need some extra powerful tool to detect the heat tolerance genes. The most powerful tool to detect the qualitative and quantitative complex traits is marker system (Roff, 1997. Shah *et al.,*1999; Kumar *et al.,* 2020).

There are many marker system has been promising to detect the QTL. There are many markers that has been most extensively utilized in plant breeding to detect the heat tolerance QTLs but in this review paper we will discuss some markers (Table No. 01) is briefly described here.

Table.1 Schematic representation of Quantitative trait loci with heat tolerance

Trait	QTL	Chromosome No.	Marker interval	Population Type	Population Size	Cross	References
Grain Yield	*$QYld.1A_1$*	1A	wPt-668205–wPt-731282	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain Yield	*QYld.1B*	1B	wPt-3465–wPt-5801	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain Yield	*QYld.3B*	3B	wPt-667607–wPt-666139	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain Yield	*$QYld.2D_1$*	2D	wPt-729831–wPt-730613	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Biological yield	*QByld.4A*	4A	wPt-2084–wPt-671844	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Biological yield	*QByld.1B*	1B	wPt-3465–wPt-5801	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Biological yield	*QByld.3B*	3B	wPt-729904-gwm247	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Thousand grain weight	*QTgw.1B*	1B	wPt-5801–wPt-2019	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Thousand grain weight	*$QTgw.2B_1$*	2B	Cfd73–wPt-8460	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Thousand grain weight	*$QTgw.2B_2$*	2B	wPt-4301–wPt-3132	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Thousand grain weight	*QTgw.3B*	3B	wPt-1484-gwm566	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QGnu.6A*	6A	gwm334–wPt-7330	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per	*QGnu.7A*	7A	gwm635–wPt-4877	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)

spike							
Grain number per spike	*QGnu.1B*	1B	wPt-3465–wPt-5801	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	$QGnu.2B_3$	2B	wPt-5795–wPt-2106	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QGnu.3B*	3B	wPt-666139–wPt-4412	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	$QGnu.6B_2$	6B	wPt-3378–wPt-6282	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QGnu.7B*	7B	wPt-9326–wPt-7975	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QGnu.1D*	1D	wPt-1799–wPt-3707	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Spike length	*QSl.7A*	7A	wPt-4877–wPt-6217	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Spike length	*QSl.1B*	1B	wPt-3465–wPt-5801	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Spike length	*QSl.6B*	6B	wPt-663764wPt-7954	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Spike weight	*QSw.1B*	1B	wPt-3465–wPt-5801	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Spike weight	*QSw.2B*	2B	Cfd73–wPt-8460	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Spike weight	*QSw.3B*	3B	wPt-5358–wPt-5390	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)

Spike weight	*QSw.2D*	2D	wPt-729831–wPt-730613	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.4A-1*	4A	wPt-665730–wPt-665927	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.4A-2*	4A	wPt-664047–wPt-669103	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.5A*	5A	wPt-665622–wPt-1954	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.1B*	1B	wPt-5801–wPt-2019	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.3B-1*	3B	wPt-5390–wPt-669328	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.3B-2*	3B	wPt-731120–wPt-664771	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.5B*	5B	wPt-3457–wPt-3661	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.7B*	7B	wPt-2025–wPt-7894	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.5D*	5D	wPt-671760–wPt-5505	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Grain number per spike	*QSpn.7D*	7D	wPt-664088–wPt-667257	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)

Stem weight	*QStw.1A*$_1$	1A	wPt-665590–wPt-672158	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Stem weight	*QStw.4A*	4A	wPt-2084–wPt-671844	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Stem weight	*QStw.1B*	1B	wPt-5801–wPt-2019	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Stem weight	*QStw.2B*$_2$	2B	wPt-3132–wPt-0950	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Stem weight	*QStw.3B*	3B	gwm247–wPt-667324	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Stem weight	*QStw.7B*	7B	wPt-2305–wPt-1149	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Stem weight	*QStw.1D*	1D	wPt-9664–wPt-7437	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Plant height	*QHt.1B*	1B	*wPt-5801- wPt-2019*	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Peduncle length	*QPdl.1A*$_1$	1A	wPt-665590–wPt-672158	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Peduncle length	*QPdl.3B*	3B	wPt-666139–wPt-4412	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Peduncle length	*QPdl.2D*$_1$	2D	wPt-9848–wPt-3757	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Peduncle length	*QPdl.7D*	7D	wPt-4254–wPt-672113	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Node number	*QNn.2B2*	2B	*wPt-4301–wPt-3132*	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Node number	*QNn.3B*	3B	*wPt-666964–wPt-731524*	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Node number	*QNn.6B2*	6B	*wPt-6286–wPt-9532*	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
Node number	*QNn.2D1*	2D	*wPt-667584–wPt-671990*	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)

Node number	*QNn.7D*	7D	*wPt-664438–wPt-663984*	RIL	186	Roshan× Superhead2	Zandipour *et al.*, (2020)
HSI Canopy Temperature	*QHCt.bhu-1DS*	1D	*wPt9664-cfd083*				Chandra *et al.*, (2017)
Chlorophyll content	-	-	*Barc68*	RIL	142	Chirya 3 × Sonalika	Kumar et. al. (2012)
Canopy temperature	-	-	*Barc101*	RIL	142	Chirya 3 × Sonalika	Kumar et. al. (2012)
Grain yield	-	-	*Gwm190*	RIL	144	Kauz × MTRWA116	Mohammadi et. al. (2008)
Flowering (days)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-2D*	2D	*Ppd-D1a -wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-2D*	2D	*wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)

Flowering (days)	*QFlt.dms-2D*	2D	*wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-2D*	2D	*wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-3B*	3B	*Excalibur_c45968_83-CAP12_rep_c7901_114*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-3B*	3B	*Excalibur_c45968_83-CAP12_rep_c7901_114*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-3B*	3B	*Excalibur_c45968_83-CAP12_rep_c7901_114*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-4A.1*	4A	*wsnp_Ex_c54453_57331510*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-4A.1*	4A	*CAP12_rep_c4000_432-wsnp_Ex_c54453_57331510*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-4A*	4A	*CAP12_rep_c4000_432-wsnp_Ex_c54453_57331510*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)

Flowering (days)	*QFlt.dms-4A.2*	4A	*Ra_c7973_1185-wsnp_Ex_c10390_17007929*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-4A.2*	4A	*Ra_c7973_1185-wsnp_Ex_c10390_17007929*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-4A.3*	4A	*BobWhite_c22176_295-RAC875_c59673_500*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-4A.3*	4A	*BobWhite_c22176_295-RAC875_c59673_500*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-5A.1*	5A	*Kukri_c20258_143-JD_c3525_1503*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-5A.2*	5A	*Tdurum_contig86202_175-wsnp_Ra_c10915_17838202*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-5A.2*	5A	*wsnp_Ra_c12183_19587379-wsnp_Ra_c3414_6378271*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-5B*	5B	*BS00063785_51-IACX5818*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-5B*	5B	*IACX5818-wsnp_Ku_c17875_27051169*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-6B.1*	6B	*Tdurum_contig11700_1247-wsnp_Ra_c2730_5190365*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)

Flowering (days)	*QFlt.dms-6B.1*	6B	*Tdurum_contig11700_1247-wsnp_Ra_c2730_5190365*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-6B.2*	6B	*wsnp_Ex_c4124_7455225- Kukri_c49331_77*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-6B.2*	6B	*wsnp_Ex_c4124_7455225- Kukri_c49331_77*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-6B.2*	6B	*wsnp_Ex_c4124_7455225- Kukri_c49331_77*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-7A*	7A	*Excalibur_c16355_712-RAC875_c18446_521*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-7A.1*	7A	*Tdurum_contig11613_329-wsnp_Ex_c30239_39179460*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-7A.1*	7A	*Tdurum_contig11613_329-wsnp_Ex_c30239_39179460*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-7A*	7A	*Tdurum_contig11613_329-wsnp_Ex_c30239_39179460*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-7A*	7A	*Tdurum_contig11613_329-wsnp_Ex_c30239_39179460*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)

Flowering (DD)	*QFlt.dms-7A.1*	7A	*Tdurum_contig11613_329 - wsnp_Ex_c30239_39179460*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-7A.1*	7A	*Tdurum_contig11613_329-wsnp_Ex_c30239_39179460*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (days)	*QFlt.dms-7A.1*	7A	*wsnp_Ra_c63822_63288359-wsnp_BG313770A_Ta_2_3*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Flowering (DD)	*QFlt.dms-7A.2*	7A	*IACX4711-wsnp_Ku_c7873_13486065*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_18*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)

			29821				
Maturity (days)	*QMat.dms-3B*	3B	*wsnp_Ku_c210_413608 - Excalibur_c45968_83*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.,* (2016)
Maturity (days)	*QMat.dms-4A.1*	4A	*CAP12_rep_c4000_432 - wsnp_Ex_c54453_57331510*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.,* (2016)
Maturity (days)	*QMat.dms-4A.1*	4A	*CAP12_rep_c4000_432 - wsnp_Ex_c54453_57331510*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.,* (2016)
Maturity (DD)	*QMat.dms-4A.1*	4A	*CAP12_rep_c4000_432 - wsnp_Ex_c54453_57331510*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.,* (2016)
Maturity (DD)	*QMat.dms-4A.1*	4A	*CAP12_rep_c4000_432 - wsnp_Ex_c54453_57331510*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.,* (2016)
Maturity (days)	*QMat.dms-4A.2*	4A	*wsnp_Ex_c5690_9994305- wsnp_Ex_rep_c67799_66488792*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.,* (2016)
Maturity (DD)	*QMat.dms-4A.2*	4A	*wsnp_Ex_c5690_9994305- wsnp_Ex_rep_c67799_66488792*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.,* (2016)

Maturity (days)	*QMat.dms-4A.2*	4A	*Ra_c7973_1185-wsnp_Ex_c10390_17007929*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-4A.3*	4A	*GENE-2307_140-RAC875_c95150_286*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-4A.3*	4A	*GENE-2307_140-RAC875_c95150_286*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-4D.1*	4D	*Excalibur_c5010_1336-Kukri_rep_c68594_530*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-4D.2*	4D	*Kukri_rep_c68594_530-Rht-D1b*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-4D.2*	4D	*Kukri_rep_c68594_530-Rht-D1b*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-4D.2*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-4D.2*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-4D.2*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-4D.2*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-4D.2*	4D	*Rht-D1b-wsnp_CAP11_c356_280*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)

			910				
Maturity (DD)	*QMat.dms-5A*	5A	*IACX3911-BS00077858_51*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-5A*	5A	*BS00077858_51-BS00067209_51*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-7A.1*	7A	*wsnp_Ra_c63822_63288359-wsnp_BG313770A_Ta_2_3*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (DD)	*QMat.dms-7A.2*	7A	*Tdurum_contig37154_190-RAC875_c14982_577*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-7A.2*	7A	*RAC875_c14982_577-Tdurum_contig20214_279*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Maturity (days)	*QMat.dms-7A.2*	7A	*RAC875_c14982_577-Tdurum_contig20214_279*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Plant height	*QPht.dms-4D*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Plant height	*QPht.dms-4D*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Plant height	*QPht.dms-4D*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Plant height	*QPht.dms-4D*	4D	*Rht-D1b-wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)

Plant height	*QPht.dms-4D*	4D	*wsnp_CAP11_c356_280910*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Plant height	*QPht.dms-4D*	4D	*wsnp_CAP11_c356_280910- BS00036421_51*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Grain yield	*QYld.dms-1B*	1B	*Tdurum_contig50988_500-wsnp_Ex_c13878_21738866*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Grain yield	*QYld.dms-2A*	2A	*Tdurum_contig86243_288- BS00063368_51*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Grain yield	*QYld.dms-2D*	2D	*Ppd-D1a-wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Grain yield	*QYld.dms-2D*	2D	*wsnp_CAP11_c3842_1829821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Grain yield	*QYld.dms-4D*	4D	*D_GDEEGVY01C7BQU_446-BobWhite_c20689_427*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Grain yield	*QYld.dms-5B*	5B	*Excalibur_c30667_102-Ku_c6193_821*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Grain yield	*QYld.dms-5B*	5B	*Ku_c6193_821-Tdurum_contig31131_198*	RIL	158	Cutler × ACBarrie	Perez-Lara *et al.*, (2016)
Thylakoid membrane damage 4/7	*QHttmd.ksu-6A*	6A	*Xbarc113/AGCTCG347*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Thylakoid membrane damage 4/7	*QHttmd.ksu-6A*	6A	*Xbarc113/AGCTCG347*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Chlorophyll content4/7	*QHtscc.ksu-6A*	6A	*Xbarc113/AGCTCG347*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Chlorophyll	*QHtscc.ksu-*	6A	*Xbarc113/AGCTCG347*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)

content 4/7	*6A*						
Thylakoid membrane damage 7/10	*QHttmd.ksu-7A*	7A	*Xbarc121/barc49*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Thylakoid membrane damage 7/10	*QHttmd.ksu-7A*	7A	*Xbarc121/barc49*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Thylakoid membrane damage 7/10	*QHttmd.ksu-7A*	7A	*Xbarc121/barc49*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Chlorophyll content 4/7/10	*QHtscc.ksu-7A*	7A	*Bin754/Bin45*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Chlorophyll content 4/7/10	*QHtscc.ksu-7A*	7A	*Xbarc121/barc49*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Chlorophyll content 4/7/10	*QHtscc.ksu-7A*	7A	*Xbarc121/barc49*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Plasma membrane damage 7/10	*QHtpmd.ksu-7A*	7A	*Xbarc121/barc49*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Plasma membrane damage 7/10	*QHtpmd.ksu-7A*	7A	*Xbarc121/barc49*	RIL	101	Karl 92 × Ventnor	Talukder *et al.*, (2014)
Plant height	*QPh.cau-1B.1*	1B	*Excalibur_c10111_85*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-1B.2*	1B	*BS00011892_51*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-1B.3*	1B	*bar308b*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-2D.2*	2D	*gwm296*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)

Plant height	*QPh.cau-2D.3*	2D	*cfd53*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-3A.1*	3A	*Tdurum_contig34075_98*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-3A.2*	3A	*CAP11_c1022_117*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-3A.3*	3A	*RAC875_c38975_411*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-4B.2*	4B	*BS00011338_51*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-4D.1*	4D	*Rht2*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-4D.2*	4D	*barc105*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-5A.2*	5A	*RAC875_c91464_170*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-6A.2*	6A	*GENE-3659_162*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-6A.3*	6A	*IAAV5035*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)
Plant height	*QPh.cau-6D*	6D	*barc54*	DH	203	ND3338 × JD6.	Guan *et al.*, (2018)

Simple sequence repeat

SSR also called the microsatellite marker, it consist of tandem repeat in DNA sequence such as mono, di, tri, tetra and so on. These tandem repeats found in both prokaryotic and eukaryotic genome (Tautz and Renz 1984; Katti *et al.*, 2001; Toth *et al.*, 2000; Salem *et al.*, 2008). They have another name such as short tandem repeats marker, microsatellites markers and sequence tagged microsatellite (STMS) marker etc. it is hyper variable marker available in nature. The variation in these markers is due to subside the DNA replication, in this there are many tandem repeats of nucleotide may be matching due to excision or addition of DNA (Schlotterer and Tautz 1992). Slippage of DNA strand during replication produces mutation than the point mutation. Microsatellite are differentiate based on unique loci called the polymorphism, it can be analysed with the help of PCR. In this technique primer used without radioactive labeled or flurolabeled or radiolabeled to know diverse group of individual with the help of PCR. This unlabeled primer is used analysis with the help of agarose gel electrophoresis or polyacrylamide gel. The unlabeled or fluorolabed primer significantly enhances the research and also panders the research (Wenz *et al.*, 1998; Kumar and Singh, 2020). SSR or microsatellite is codominant in nature or distinguished to heterozygous from homozygous and they are also highly reproducible due to locus specific. There are many scientists has been described the which one particular marker for heat tolerance.

In conclusion, there are more variation for heat tolerance that is varies on development and growth stage but for wheat, reproduction and grain filling stage is more prone to high temperature. Various plant parts are affected by the cellular responses. Therefore to increase yield in wheat during high temperature we will have to understand the idea about heat tolerance mechanism in plants. Molecular marker in plant breeding to detect QTLs for trait of interest is used. But in this review paper, we have described QTLs for heat tolerance. It seems that this technology reveals about the reliable information without any false report.

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