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Concept, Characteristics and Future of Cold-type Wheat

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Cold types of wheat are the kinds of wheat whose canopy temperature keeps slightly lower and has a series of advantageous traits, which are favorable for wheat to have high and stable yield and stable high quality. The paper expatiates on the advances and important problems in the research of cold types of wheat and predicts the future of cold types of wheat and the influences of the research about cold types of wheat on other crops and plants.

Key words cold types of wheat, some important problems, prospect

Infrared thermometry began to involve gradually in plant temperature research in 1960s[1] and because it is quick, highly sensitive and low in error it has been quickly adopted in many fields of agricultural research. At the beginning, wheat research mainly dealt with the effects of environmental stresses, especially water stress, on canopy temperatures of same genotypes of wheat and by now it has been continuing for more than 40 years having obtained many achievements. The research aiming at comparing canopy temperatures of different genotypes of wheat under same ecological environments began to become active in 1980s and has remained so until now. Many international and domestic scholars have found in their research that wheat can be divided into slightly lower and slightly higher canopy temperature wheats and wheat materials whose canopy temperatures keep slightly lower has some advantageous physiological characteristics which are very favorable for wheat to have a high yield[2-5]. These findings had stimulated the interest in carrying out further inquires about the genotypes of wheat whose canopy temperatures keep slightly lower. In order to smooth the identification of slightly lower and slightly higher canopy temperature wheats and favor the breeding of improved wheat varieties, Chinese scholars have classified wheat genotypes depending on canopy-temperature patterns of wheat[6-9], and carried out in-depth and all-round studies revealing some regular patterns of academic importance and productive significance and thus enhancing the research about wheat with a slightly lower canopy temperature.

1 Concept of cold-types of wheat

Cold types of wheat are defined as the kinds of wheat that maintain a slightly lower canopy temperature at the kernel-filling stage (flowering-maturing) in some ecological area of wheat compared with the control varieties, wheat varieties that are dominantly adopted for long in the area; and in contrast to cold types of wheat, warm-types of wheat are defined as the kinds of wheat that maintain a slightly higher canopy temperature at the kernel-filling stage (flowering-maturing) in some ecological area of wheat compared with the control varieties, wheat varieties that are dominantly adopted for long in the area. Some kinds of wheat are similar to cold-type wheat (cold pattern) in canopy temperature pattern in some years, and some kinds of wheat are similar to warm type wheat (warm pattern) in canopy temperature pattern in some years; some kinds of wheat present a pattern in which their canopy temperature appear higher at first and then lower (cold-tail pattern), a pattern in which their canopy temperature appear lower at first and then higher (warm-tail pattern) or a more complex pattern and these kinds of wheat are categorized as intermediate temperature types of wheat. Intermediate temperature types of wheat have a variable canopy temperature and are polymorphic. In current production, most kinds of wheat are intermediate temperature types, while warm types of

wheat whose canopy temperatures keep slightly higher for a long term and cold types of wheat whose canopy temperature keep slightly lower for a long term are in much smaller quantities. In any ecological area of wheat, all the wheat materials can be classified into the above three categories according to their canopy temperature patterns without exception.

The use of wheat varieties dominantly adopted for long as the baselines standard to divide wheat into cold types, warm types and intermediate types is based on such considerations as follows: the long-time local adoption of one wheat variety indicates that the variety can harmoniously grow with the world of nature and although it may suffer some disastrous weathers such as drought, hot and dry wind, and overcast and rainy weather, and some biological attacks such as disease and insect attacks, it adapts itself to survive and presents a high yield, stable one in particular, together with some quality advantages so that people are always unwilling to give it up. Our study has adopted Xiaoyan 6 as the control variety for a long time because the variety, as is well known, developed through distant hybridization by Academician Li Zhensheng and his group, enjoyed great popularity and was adopted in production for 30 years, true to its "long-lasting recognition". Because the varieties like this one display their strengths and uniqueness in their population, individual plants, cellular microscopic and ultra-structures, especially strong adaptabilities and high capacities in their metabolic functions, to choose them as the measurement yardsticks is actually to set up vigorous and adaptable yardsticks and then it is of great significance to compare others with the yardsticks to test if others are equal to or surpass the yardsticks.

Long term studies have found that the temperature patterns of wheat are closely related to the metabolic functions of its plants. Comparatively speaking, cold types of wheat have the best and stable metabolic functions, warm types of wheat take the second place and intermediate temperature types of wheat vary much in their metabolic functions, appearing closely to cold types of wheat in their metabolic functions while they present a cold pattern in some years and close to warm types of wheat in their metabolic functions while they present a warm pattern, as if they were not stable swinging between warm types and cold types of wheat. In such a way, canopy temperature is endowed with the significance of an indicator and the comparison with canopy temperature of a control variety can determine the vitalities and adaptabilities of other varieties under study.

Different genotypes of wheat show their differences in canopy temperature as early as heading-flowering time, but the differences are more remarkable at the kernel-filling/kernel setting stage; the kernel-filling/kernel setting stage is the final but crucial time for yield formation of wheat and thus much attention should be paid to it.

Canopy temperature is a very sensitive factor and thus it is necessary to take into account scientifically, especially comparability, in its observation. If wheat materials greatly differ in their growth period, for instance, they should be classified into the groups of early maturity, medium maturity and late maturity in observing and comparing their canopy temperatures.

2 Biological characteristics of cold types of wheat

Cold types of wheat display their biological characteristics in the forms of strong metabolic functions and advantageous cellular structures, which forms metabolic and structural basis of wheat producing a high and stable yield.

2.1 Metabolic functions

Long-time measurements have revealed that cold types of wheat are superior to intermediate temperature types and warm types of wheat in leaf functional period, and chlorophyll, protein, solvable protein nitrogen contents, NR, SOD, CAT and POX activities, transpiration rate and net photosynthetic rate functional leaves, root vitality and seed plumpness, displaying that cold types of wheat have such characteristics as stronger vigor, weak early aging and even nil early aging and strong late-growing capacity; these characteristics are superior not only to those of warm types of wheat but also to intermediate temperature types of wheat that dominates in wheat production, and because the latter fluctuates in some important traits, cold types of wheat, comparatively speaking, appear more stable.

2.2 Cellular microscopic structures and ultra-structures

Cold types of wheat have leaves whose mesophyll are composed of many layers of small and closely arranged cells, and their leaves contain great numbers

of closely arranged chloroplasts in which there are dense stroma, many grana with well developed lamellae and large cross-section areas of narrowly spaced vascular bundles, and high numbers and high cross-section areas of vascular bundles per unit leaf cross-section width; the internodes beneath the spikes and the second internodes from the spikes have high numbers of vascular bundles per unit of their cross-section areas and high ratios of vascular bundle cross-section to the stem cross-section. These contrast sharply with warm types of wheat having the highest canopy temperature in all wheats. The above mentioned structural characteristics that cold types of wheat have are capable of raising leaf photosynthetic efficiency and conducive to timely transport of photosynthates away from leaf cells and timely transport of soil water and inorganic salts to various leaf parts, and this is the structural basis of cold types of wheat having strong vigor, strong transpiration and low plant temperature.

2.3 Ecological adaptabilities

Long time repeated experiments of wheat under drought, hot and dry wind and overcast and rainy weather (including the experiment to plant a group of wheat materials in Weibei Dryland Highlands and the region of the lower reaches of Yangtze river suffering severe water-logging due to overcast and rainy weather, respectively) have indicated that cold types of wheat not only perform well under normal weather but also perform prominently under sharply contrasted meteorological condition, drought and overcast and rainy weather, and compared with intermediate temperature types and warm types of wheat they maintain a slightly lower canopy temperature while keeping their superiorities in the internal and external characters mentioned previously and varying steadily. This is a two-fold adaptability of high value to both drought and overcast and rainy weather, which is of great significance for wheat to have a high yield, especially stable one.

Some people are worrying whether cold types of wheat can maintain a proper transpiration for their normal life activities under water insufficiency because cold types of wheat have well developed roots and strong long-lasting transpiration and this would inevitably results in them absorbing more soil water. The measurements that we conducted in many years have indicated that although cold types of wheat relatively absorb more soil water, they can not result in soil moisture that is poorer than what other temperature types of wheat lead to. For example, cold types of wheat do not cause soil water contents in various soil layers to differ statistically significantly from what warm types of wheat lead to, and then what is the reason for this? The reason is the canopy effects. Cold types of wheat have large sizes of vigorously growing canopies thus reducing the evaporation of soil water from ground surface, increasing soil water that get into atmosphere through plant transpiration and decreasing soil water that get into atmosphere through evaporation, and obviously these favor wheat to maintain strong transpiration and low canopy temperature. In addition, these reveal once again that even under drought, canopy temperature is an indicator to tell if wheat had strong adaptability.

2.4 Reasons of the canopy temperature differences of different temperature types of wheat

The classification of wheat into 3 temperature types results from mutual actions of external and internal factors. External factors are mainly the influences of the second heat source (ground surface) on wheat populations. According to the observations conducted in many years, the second heat sources of cold types of wheat have remarkably lower temperature and weak infrared radiation and consequently they do not have a strong capacity to warm up their canopies; in contrast with the second heat resources of cold types of wheat, the second heat sources of warm types of wheat have remarkably higher temperature and strong infrared radiation thus able to exert strong heating influences on their canopies. Obviously, this closely relates to that warm types of wheat have poor vigor, severe early aging and high sunlight transmissivity, high solar radiation absorption, thus resulting in their second heat sources having higher temperature. Internal factors mainly mean the vitalities of wheat plants and then they are of fundamental significance. Wheat vitality is the comprehensive reflection of metabolic processes in plant bodies and these processes exert influences on wheat vitality through their mutual relations, actions and limitations. Plant transpiration directly exerts influence on canopy temperature. Cold types of wheat have strong and long-lasting transpiration and thus according to heat balance equation, net radiation $R = P + B + LE + IA + Q_T + Q_A$, if most of net radiation R is consumed on transpiration latent heat LE, then the leaf-heating and stem-heating energies Q_T and Q_A will inevitably decrease thereby resulting in the canopy having slightly low temperature; warm types of wheat

have an opposite picture that if LE relatively decreases, Q_T and Q_A will relatively increase resulting in the canopy having slightly high temperature. Strong or weak plant transpiration is a reflection of high or low plant vitality instead of an isolated phenomenon and closely related to root development, nitrogen and carbon metabolisms and active oxygen species metabolism and consequently that high or low canopy temperature is an external signal of strong or poor metabolic functions to some extent and it has theoretical and practice basis. Besides, external and internal factors are closely related. Cold types of wheat have strong vigor and age slowly and consequently their stems and leaves appear vigorous, having a large green area that declines slowly and leaking relatively less sunlight and resulting in the second heat resource having low temperature; while this relatively low ground temperature exerts influence on the canopies, wheat aging lessens due to its weak heating effect, which more favors the canopies to have a slightly low temperature. In such way, a beneficial and interactive cycle between wheat plants and environments forms, and it follows that plant vitality is of crucial significance for the canopies to have high or low temperature.

3 Significance of cold types of wheat for wheat to high and stable yield and high quality

Advantageous biological characteristics of cold types of wheat lay down a structural and physiological foundation of wheat having stable and high yield and high quality, but the realization of wheat having stable and high yield still need to combine "cold character" of cold types of wheat with other important factors concerned and in this way cold types of wheat can be put into full play.

3.1 High yield

In our experiments, there are typical cold types of wheat, for instance, Xiaoyan 6, Shaan 229 and 901, which were the wheat varieties enjoying great popularity. They had stable and high yields and won great favor in rather great limits, but as they were taken over by other varieties having higher yields and then relegated from the viewpoint of yield. What was the reason for this? The reason was diverse, but it is clear that their potential sink capacities were not high enough in terms of their yield component. The formula of potential sink capacity is Potential sink capacity = spike number per unit area × kernel number per spike × maximum average size per fresh kernel. The maximum size of fresh kernels appear at the later milky stage (the eve of the dough stage), and thus the multiplication product of the three actually reflects the potential storage capacity of the kernels per unit land area at which a variety stores nutrients, simply speaking, how large a storage place is built. Although the potential sink capacity only appear in a very short period of kernel filling stage, it is of great significance because it determines the yield frame of a variety and the higher sink capacity the variety, the more possible it is for the variety to get a high yield; it is essentially impossible for a variety with a low potential sink capacity to reach a high yield. For this, we argue that potential sink capacity is the first important factor in structural basis of yield formation and the realization of high yield. According to the above formula, the potential sink capacity depends on all the tree terms and this means that potential sink capacity can be diversely raised. You can determine which of the terms should be in a priority position according to climate, soils, farming practices and breeding experiences, nevertheless, no matter which spike size, spike number or both spike size and spike number you decide to put on priority, the multiplication product of the three terms should be high, which is the final consideration for the yield frame.

While maintaining a low lasting canopy temperature, cold types of wheat have strong root vigor, vigorous leaf metabolisms and high late growing capacity so that they can create strong substance flow, and this is conducive to realize the potential sink capacity; however, if some cold type of wheat have a potential sink capacity not high enough, thereby getting a yield not so high, this is because something is wrong with its potential sink instead of the fault of "cold character". In production, technically speaking, there are no big barriers in creating a sink with high capacity. According to our estimations, it needs a potential sink capacities of about 12.75 cubic meters or 13.95 cubic meters to obtain respectively a yield of 9000 kg or 9750 kg of kernels per hectare and this can be done, but the question is what kinds of wheat have the ability to realize so big a potential sink; it is clear that only those kinds of wheat that have strong root vigor, strong aboveground metabolisms, strong late growing capacity and strong adaptability to stressful conditions are possible to fulfill the duty and cold types of wheat seem to be the proper candidates. Therefore, in this sense, it is not overstated that the competition among the future varieties is actually the vigor competition of

their plants. Once these are fully understood, a new model for wheat to get a high yield ensues, which is the model of "high potential sink capacity + cold state of wheat". In our opinion, this model will have a bright prospect in the future.

While efforts are made to create large sinks and cold plants, much attention should be paid to lodging prevention, and disease and pest prevention and control. However, large sinks and cold plants are essentially important from the viewpoint of high yield and worth thinking over. Besides, there is a piece of information hinted that cold types of wheat, which are capable of keeping a slightly low canopy temperature year by year, either do not lodge or lodge in some years but at not so severe a level; they either suffer light disease and pest attack and even are immune to the attack, or suffer the attack in some years but at a controllable level. Because the canopy temperatures will quickly rise once severe lodging and severe disease and pest attacks take place, it is impossible to maintain their low canopy temperatures, which tells us at another angle that the kinds of wheat that are classified into cold types of wheat usually do have the traits that help them suffer no lodging or resist lodging and suffer light disease and pest attack and consequently they can maintain their slightly low canopy temperature to continue; these traits are the accompanying ones with low canopy temperature and favorable for high yield.

3.2 Yield stability

Just as production practices have indicated, Xiaoyan 6 mentioned before is well-known to have kept its yield stable for 30 years and although it had not been the local control variety, we still treasure its "cold character", why? The reason for this is that cold types of wheat show strong vigor not only in normal years but also in adverse years so that they avoid sharp yield fluctuations. But other temperature types of wheat, for instance, intermediate temperature types of wheat, can not keep their vigor stable, tending to be cold types of wheat in favorable environments and to be warm types of wheat in adverse environments and thus how can they maintain their yields stable while they swing in their vigor like this? Now there are some wheat varieties not capable of maintaining their high yields stable and this problem probably arise from their temperature patterns; in the yield frame characterized by a unstable temperature pattern, how it is possible to get a stable yield! In order to get a high and stable yield, it is worthwhile to try to transform wheat varieties into cold types of wheat.

3.3 Quality

In the recent years, wheat quality has attracted much concern, but instead of being a general concept, "high quality" should be defined according to the uses of wheat. for example, high-and strong-gluten varieties of wheat can be planted for high quality bread making, their flours are not suitable for cake making, which needs low-and weak-gluten wheat varieties. So wheat quality depends on final uses of wheat. As to this question, the most prominent characteristic of cold types of wheat is the constant character of their quality traits. Production practices show that wheat varieties are planted either for bread making, steamed bread and noodle makings or for cake or crisp cake making, their qualities are affected by their environments and it often occurs that some of the varieties degenerate from high-quality ones to poor quality ones and as a result their wheat qualities are severely damaged. Experiments conducted in many years have proved that in contrast with intermediate temperature types and warm types of wheat, cold types of wheat generally vary very slightly in keeping their quality traits, which, clearly, is closely related to stable metabolisms and structures and biological inertia of cold types of wheat. Therefore, it is probably an effective way for geneticists and breeders to set cold types of wheat as one of their predetermined goals in their efforts for improving quality stabilities of the wheat varieties that they breed.

In summary, cold types of wheat have clear advantages in yield and quality, and thus it is possible to integrate high and stable yield and high and stable quality in cold types of wheat so that the loose and poor integration of high and stable yield and high and stable quality will be rectified, which is clearly of great importance.

4 Future

Whether from academic or productive angle, cold types of wheat have a bright future. At first, from science angle, they probably evolve into a research field as a growing point of knowledge—the exploration of basic biological characters and ecological adaptabilities of a great group of plants with cold and low temperature character. By now, international and domestic scholars have found that there exist cold pattern in some genotypes of a great batch of plants such as corn, sorghum, rice, cotton, legumes, pota-

to, sunflower and couch and it widely and highly relates to high productivity; this has stimulated great interest, nevertheless, cold characters and their mechanisms of all these plants except a few plants including wheat are not clearly and deeply understood in general. Therefore, the exploration of cold types of wheat will inevitably enhance the researches about these cold types of plants and depending on common and unique characters of these cold types of plants, these researches will gradually reveal biological secrets hidden in these cold genotypes and evolve a unique knowledge system of cold types of plants.

Seen from the angle of production practice, canopy temperature measurement and cold phenomenon discovery of wheat have indeed opened a new way for wheat breeding, and more important or more worthwhile, cold germplasm, which people did not know in past but exist in the world of nature for ages, has been revealed by canopy temperature measurement. This germplasm is cold types of wheat discussed previously. Although the gene or serial genes controlling "cold character" have not been clearly defined, it is clear and sure that "cold character" follows basic inheritance patterns. For example, cold types of wheat can transfer "cold character" from one generation to another generation and the involvement of cold parent will be conducive to producing cold offspring, like Xiaoyang 6, Shaan 229 and 901, the cold types of wheat mentioned previously, whose parents are found to include the materials having a clearly and slightly low temperature. Furthermore, if two warm wheat materials are crossed, nearly all of their progenies show warm character and "cold character" is difficult to occur. These are genetic results rather than random ones. Therefore, low temperature germplasm of wheat has indeed become a kind of germplasm and is worth exploiting.

Upon the entry of the 21st century, higher requirements of wheat production have been set so that the voices demanding to create super-high yield wheat can very often be heard and then many experts, scholars and agricultural scientific workers have been making strenuous efforts to probe in many aspects. Under these circumstances, it seems that more attention need to be paid to the materials of wheat that have been understood or been under study and their temperature patterns and accompanying biological characteristics, and the materials of wheat development with these materials and their temperature patterns and accompanying biological characteristics; this will not only open a new thinking approach in mentality but also make improved variety breeding have clearer and deeper orientation and that infrared thermometry adoption will bring about many conveniences in operation. We think that cold character should be gradually integrated in wheat production though a series of work. So-called "cold character integration" essentially means temperature reduction, which should embody not only in corresponding farming practices to be adopted but also in temperature characteristics of the varieties to be bred, that is to say, no matter what kinds of breeding methods, system selection, cross selection, haploid breeding or radiation breeding, heterosis exploitation or outer space mutagenesis, you adopt, and if your wheat varieties bred previously are warm types, you should consider that would-be new varieties be bred as intermediate temperature types whose temperature will be generally low; if the varieties of wheat that you adopt are intermediate temperature types characterizing warm tail pattern, you can that the would-be new varieties be bred as intermediate temperature types characterizing mainly cold tail pattern or cold pattern, etc, and as a matter of course you had better directly breed cold types of wheat. In summary, "cold character" is the essence of wheat producing high and stable yield and having high and stable quality and then it needs to be carefully manipulated in practice. "Cold character integration" needs not spend a long time, nonetheless, it is the first step and then there will come the advanced development which will create a batch of cold types of wheat that adapts to local conditions. We believe that as cold character integration of wheat starts and marches forward, it will contribute to wheat production at a higher level and help to improve a batch of other crops and plants in productive capacity.

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