A Map of the World for

Wheat Breeding

CIMMYT wheat breeders have a different map of the world than the rest of us.

Their map is a mosaic of growing environments, each with distinct characteristics that influence wheat production.

Most wheat breeders have a fairly narrow scope of operations, but those at CIMMYT breed wheat for the entire developing world. This is a tall order: wheat is grown on about 110 million hectares in more than 70 developing countries, so CIMMYT breeders must understand how factors such as temperature, rainfall, diseases, and pests vary. They need to know which characteristics are essential in wheat varieties intended for specific parts of the world, and they must also understand how individual wheat varieties—and ultimately wheat production—are likely to be affected by growing conditions in the various environments.

In the 1980s, CIMMYT's wheat breeders began to codify their vision of the developing world's wheat growing areas into a standard set of "mega-environments." The mega-environments were defined by crop production factors (temperature, rainfall, sunlight, latitude, elevation, soil characteristics, and diseases), consumer preferences (the color of the grain and how it would be used), and wheat growth habit (see "Habits of Highly Successful Wheat Varieties," inside back cover). Researchers identified six mega-environments for spring wheats and three each for facultative and winter wheat (see table). Most wheat grown in developing countries is spring wheat, though China, Turkey, and parts of Central Asia, for example, have large areas of winter and facultative wheat.

Description of global wheat mega-environments. Climatic criteria are based on conditions during the coolest, warmest, or wettest consecutive three months of the year and annual means or totals.

Mega-environment	Description	Representative sites
Spring Wheat		
ME1: Favorable, irrigated low rainfall. Estimated area: 36 M ha.	Well irrigated, low rainfall regions. Conditions during the cropping season range from temperate to late heat stress, especially with late sowing. Predominantly winter-sown, tropical to subtropical. Rarely, spring-sown cool temperate regions. White-grained types predominate.	Gangetic Valley, India; Indus Valley, Pakistan; Nile Valley, Egypt; Yaqui Valley, Mexico.
ME2: High rainfall. Estimated area: 8 M ha.	Regions where crops experience no or minor moisture deficits.	
ME2A: Highland, summer rain. Estimated area: 2 M ha.	Highland regions of the tropics and subtropics where crops are grown on summer rainfall. Red grain type except white for Ethiopia.	Kulumsa, Ethiopia; Toluca, Mexico.
ME2B: Lowland, winter rain. Estimated area: 6 M ha.	Highland regions of subtropical and warm temperate regions where crops are grown on winter rainfall. Red grain type.	Izmir, Turkey; Pergamino, Argentina.
ME3: High rainfall, acid soil. Estimated area: 2 M ha.	Similar to ME2 but for regions with acid soils. Red grain is generally preferred except in the Himalayas.	Passo Fundo, Brazil; Mpika, Zambia.
ME4: Low rainfall. Estimated area: 14 M ha.	Three types of moisture deficits, based on developmental stage when moisture deficits occur, are recognized as sub-environments.	
ME4A: Winter rain or Mediterranean-type climate. Estimated area: 8 M ha.	Regions with a Mediterranean climate with post-flowering moisture deficits and heat stress typical. Late season frosts may occur. White grain is preferred.	Aleppo, Syria; Settat, Morocco.
ME4B: Winter drought or Southern Cone-type rainfall. Estimated area: 3 M ha.	Associated with pre-flowering moisture deficits. Red grain preferred to reduce sprouting.	Marcos Juárez, Argentina.
ME4C: Stored moisture. Estimated area: 3 M ha.	Sown after monsoon rains, resulting in continuous, Indian Subcontinent-type drought. Only white grain is accepted.	Dharwar, India.
ME5: Warm.		
ME5A: Warm, humid. Estimated area: 8 M ha	Warm, humid, lowland tropical to subtropical regions.	Joydebpur, Bangladesh; Encarnación, Paraguay.
ME5B: Warm, dry. Estimated area: 1 M ha.	Warm, semiarid to arid tropical to subtropical regions.	Kano, Nigeria; Wad Medani, Sudan.
ME6: High latitude (> 45 °N or S). Estimated area: 50 M ha.	Cool temperate regions of North America, Europe, and Asia where wheat is spring-sown as winters are too severe for survival of even winter wheat.	
ME6A: High-rainfall.	Humid regions of western and central Europe and of eastern Asia with winter conditions too severe for winter wheat.	Harbin, Heilongjiang, China.
ME6B: Semiarid.	Dry regions of central and eastern Asia and the northern plains of Canada and the USA with winter conditions too severe for winter wheat.	Astana, Kazakhstan.
Facultative Wheat		
ME7: Favorable, moderate cold, irrigated.		Zhenzhou, Henan, China.
ME8: High rainfall (> 500 mm), moderate cold.		Temuco, Chile; Corvallis, Oregon, USA.
ME9: Semi-arid, moderate cold, low rainfall.		Diyarbakir, Turkey; Vernon, Texas, USA.
Winter Wheat		
ME10: Favorable, cold, irrigated.		Beijing, China.
ME11: High rainfall, cold.		Cambridge, UK; Krasnodar, Russia.
ME12: Semi-arid, low rainfall, cold.		Ft. Collins, Colorado; Manhattan, Kansas, USA.

When your job is to breed wheat for the entire developing world, how can you meet specific needs in specific regions?

CIMMYT wheat breeders plan crosses between varieties with the different mega-environments in mind. By focusing on key characteristics for each mega-environment, breeders can reach their objectives more efficiently. For example, farmers in high-rainfall environments need wheat that resists as many as eight diseases, whereas fewer and different diseases are important for their counterparts in droughty areas.

Once the actual breeding process has come to an end, experimental wheats destined for a certain mega-environment are tested under those conditions. They are selected for additional improvement only if they can withstand the particular stresses predominating in that environment. Mega-environments therefore help CIMMYT's breeders set priorities for their research, which is important when they serve such a large area.

The results of this approach have been impressive. CIMMYT-related wheat varieties are planted on more than 64 million hectares in developing countries—more than three-fourths of the area planted to modern wheat varieties in those countries. In other words, CIMMYT wheat breeders have been extremely successful in developing wheat for a multiplicity of environments.

With the advent of geographic information systems (GIS), researchers have gained a means to visualize these important growing environments in greater detail, though it is not a simple matter to map the mega-environments. Jeff White, head of CIMMYT's GIS and Crop Modeling Laboratory, recently revised the mega-environment classification, primarily using climate data (see map, previous page).

"Chasing down mega-environment classifications for each site required several rounds of consultation with wheat scientists," White says. "Not surprisingly, nailing down precise locations was a challenge—names of research sites sometimes bear no relation to nearby towns or cities. But with this database in place, we can address the challenge of delineating the mega-environments as regions based on quantitative criteria for climatic and soil conditions."

The head of bread wheat breeding at CIMMYT, Maarten van Ginkel, worked closely with White to revise the mega-environments. He appreciates the potential of GIS techniques to help breeders develop varieties with the precise traits that farmers and consumers want. "With GIS, we can go beyond classical maps based on political boundaries, rainfall, and temperature. For example, we can visualize the geographical extent of trends in climatic change, projected pathways for wind-borne wheat diseases, human demographic and migration trends that affect wheat consumption, urban-rural zoning developments, and perhaps even new consumer preferences," he says.

Over the past 40 years, CIMMYT's wheat breeders have increasingly refined their breeding goals based on their comprehensive experience of conditions in the developing world. Now GIS techniques offer a way to test some of the assumptions behind their breeding goals. "We want to do more than simply confirm what we already know," says van Ginkel. "I hope that using GIS will teach us some things we do not know, or identify assumptions that are incorrect, so we can become better at what we do."

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Habits of Highly Successful

Wheat

Varieties

Almost everyone knows about the two main kinds of wheat—bread wheat and durum wheat—but few are aware that wheat also has three distinct growth habits: spring, winter, and facultative. A variety's growth habit limits its survival to certain geographic areas, mostly defined by latitude, which is why growth habit is fundamental to CIMMYT's classification of wheat growing environments.

Spring-habit wheats have a continuous growth cycle with no inactive period. In areas where winters are severe, such as northern Kazakhstan or Canada, wheat is planted in the spring after there is no risk of frost. In areas with very mild winters, such as India or Australia, spring wheat is sown in the autumn and grows through the winter.

Winter-habit wheats evolved to withstand low winter temperatures, such as those that prevail in North Korea or northwestern Europe. To flower, they require exposure to cold during their early growth. Winter wheats are sown in autumn and start to grow before winter sets in, when they become inactive. The plants resume rapid growth in the spring as temperatures rise.

Facultative-habit wheats tolerate cold more than spring wheats and less than winter wheats, but they do not require extended exposure to cold temperatures to reproduce. These wheats are found in transition zones between true spring and winter wheat regions.

Because these types of wheat have become adapted to contrasting climatic conditions, each has developed resistance or tolerance to stresses common in those conditions. These kinds of wheat probably also have distinct genes for high and stable yield. In some cases, the special genetic advantages of one wheat type can be useful in other wheat types. For example, some of CIMMYT's highest-yielding wheats have resulted from crosses between spring and winter wheats that exploited the yielding ability and stress resistances/tolerances of both wheat types. "This breeding approach brings genes together in completely novel combinations," says van Ginkel. "The genes were already widely present, but they were in geographically distinct—and often distant—locations."