# VII. Agriculture

## 1 Engineering research fronts

### 1.1 Development trends in the top 10 engineering research fronts

The top 10 engineering research fronts assessed by the field of agricultural engineering research are classified into the following three categories.

In-depth established research fronts: "impact of climate change on crop production" of agricultural resource science, "soil microbial diversity and biological nitrogen fixation" of applied ecology, "plant diversity and global biosecurity" of applied ecology, "plant diversity and global biosecurity" of agricultural resource science, "heavy-metal pollution in soil and stress on crops" of agricultural resource science, "crop nutrition supply and agricultural sustainable development" of crop science, and "impact of forest structure on forest carbon cycle" of forestry engineering.

Newly emerging research fronts: "crop breeding by molecular design" of crop science, "intelligent agricultural equipment" of agricultural engineering, and "mechanism of plant response to biotic and abiotic stress" of agricultural resource science.

Ground breaking research front: "CRISPR/Cas9 genome editing in agricultural biotechnology" of agricultural bioengineering.

Important research fronts are established by a number of core papers, with an average of 123 papers per front. The highest number of papers (491) was written in the area of the "intelligent agricultural equipment" and the lowest number of papers (18) was in the area of "response mechanisms of plants to biotic and abiotic stress." the majority of the surveyed papers were published in August 2014 (Table 1.1.1) with the average number of citations per papers 82 times greater. During 2012–2017, there were no obvious changes in the number of papers published for eight of the 10 research fronts. However, the number of published papers in the area of the "CRISPR/Cas9 genome editing in agricultural biotechnology" and the "intelligent agricultural equipment" showed a clear increasing trend (Table 1.1.2).

Table 1.1.1 Top 10 engineering research fronts in agriculture

| No. | Engineering research front | Core papers | Citations | Citations per paper | Mean year | Percentage of consistently-cited papers | Patent-cited papers |
|---|---|---|---|---|---|---|---|
| 1 | Crop breeding by molecular design | 70 | 5 829 | 83.27 | 2014.23 | – | – |
| 2 | CRISPR/Cas9 genome editing in agricultural biotechnology | 157 | 17 299 | 110.18 | 2015.20 | – | – |
| 3 | Intelligent agricultural equipment | 491 | 2 213 | 4.51 | 2015.37 | – | – |
| 4 | Impact of climate change on crop production | 63 | 6 457 | 102.49 | 2014.51 | – | – |
| 5 | Soil microbial diversity and biological nitrogen fixation | 215 | 18 377 | 85.47 | 2014.54 | – | – |
| 6 | Plant diversity and global biosecurity | 70 | 6 190 | 88.43 | 2014.74 | – | – |
| 7 | Heavy metal pollution in soil and stress on crops | 26 | 2 639 | 101.50 | 2015.12 | – | – |
| 8 | Crop nutrition supply and agricultural sustainable development | 60 | 4 028 | 67.13 | 2014.65 | – | – |
| 9 | Mechanism of plant response to biotic and abiotic stress | 18 | 1 330 | 73.89 | 2014.61 | 55.60% | 0 |
| 10 | Impact of forest structure on forest carbon cycle | 56 | 5 695 | 101.70 | 2014.34 | – | – |

Table 1.1.2 Annual number of core papers published for each of the top 10 engineering research fronts in agriculture

| No. | Engineering research front | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| 1 | Crop breeding by molecular design | 15 | 11 | 14 | 10 | 13 | 7 |
| 2 | CRISPR/Cas9 genome editing in agricultural biotechnology | 7 | 17 | 26 | 32 | 38 | 37 |
| 3 | Intelligent agricultural equipment | 26 | 44 | 71 | 73 | 133 | 144 |
| 4 | Impact of climate change on crop production | 8 | 13 | 11 | 12 | 8 | 11 |
| 5 | Soil microbial diversity and biological nitrogen fixation | 38 | 34 | 34 | 31 | 38 | 40 |
| 6 | Plant diversity and global biosecurity | 11 | 9 | 10 | 12 | 13 | 15 |
| 7 | Heavy metal pollution in soil and stress on crops | 1 | 5 | 3 | 5 | 5 | 7 |
| 8 | Crop nutrition supply and agricultural sustainable development | 10 | 6 | 9 | 15 | 10 | 10 |
| 9 | Mechanism of plant response to biotic and abiotic stress | 1 | 3 | 4 | 4 | 6 | 0 |
| 10 | Impact of forest structure on forest carbon cycle | 9 | 12 | 6 | 13 | 12 | 4 |

The top 10 engineering research fronts are summarized below based on the number of publications.

### (1) Crop breeding by molecular design

Molecular-design breeding of major crops belongs to the field of crop science, and is a newly emerging research front. Generally, molecular-design breeding can be divided into directed, systematic and designed molecular breeding. More precisely, molecular breeding integrates the physiological, biochemical, biostatistical and genetic information of the crop-breeding process using bioinformatics as the platform, and the genomic and proteomics databases are used as its foundation. First, the optimal breeding program for a specific crop is designed based on the breeding target and the growth environment. Next, molecular breeding experiments are conducted. Molecular breeding is a technique that integrates multiple scientific and technological areas to simulate and optimize various factors during the breeding process. It identifies the optimal genotypes that are required to meet the breeding objectives, and provides parent- and progeny-selection strategies for achieving the desired genotypes. Molecular breeding significantly improves the predictability and effectiveness of crop breeding, thus transforming the conventional “experimental breeding” into a highly effective “precision breeding.”

### (2) CRISPR/Cas9 genome editing in agricultural biotechnology

The clustered regularly interspaced short palindromic repeats/CRISPR-associated protein (CRISPR/Cas9) genome editing belongs to the field of agricultural bioengineering. This disruptive technology is a ground breaking research front. Genome editing technology involves the use of endonucleases to cleave deoxyribonucleic acid (DNA) at specific sites, producing double-strand DNA breaks, thus inducing DNA-damage repair. The result is a targeted gene modification. CRISPR/Cas9 is an accurate, highly efficient, and versatile genome-editing tool. CRISPR is a repetitive sequence of regular, clustered, short palindromes that are present in bacteria and archaea. This naturally occurring, ancient defense mechanism relies on a ribonucleic acid (RNA)-guided Cas9 protein to recognize and cut the target sequence, creating a double-strand DNA break. This is a highly specialized immune response mechanism that allows an organism to resist the invasion of foreign genetic material, such as plasmids and viruses. CRISPR/Cas9 technology speeds up the breeding process, solving the problem of the long generation-time encountered in standard breeding.

### (3) Intelligent agricultural equipment

This is a newly emerging research front in the field of agricultural engineering. The development of intelligent control technology for agricultural equipment focuses on the development and expansion of information technology for use in sensors, communication systems, computer vision and image-processing. Examples for sensors include those used for vehicle steering, lowering and raising of surface implements, hydraulic systems for position and pressure-depth. Examples for image monitoring systems include those used for maturity determination based on crop characteristics, seedling thinning and weeding devices that utilize integrated image processing with a visual-sensing function (automatic visual inspection systems), and computer vision and image-processing technology (stereoscopic vision systems) used during the coordinated multi-machine operation of combine harvester-grain cart systems (consisting of the radio load-control of harvester-granary and grain-conveyor speed controllers) to improve the threshing mechanism and the grain-collection performance of combine harvesters.

### (4) Impact of global climate change on crop production

This is an in-depth established research front in the field of agricultural resources science. Global climate change or global warming refers primarily to the rise in the average temperature of the global climate system owing to the excessive emission of greenhouse gases, such as carbon dioxide, due to human activity. Global climate change is expected to ① change the growth environment, seriously affect crop production and sustainable agricultural development, ② impact crop cultivation areas and change cropping systems, and ③ affect the cost and management methods of agricultural production. To cope with the impact of climate change, new strategies, theories, methods and technologies are required to establish new scientific, technological and production systems for crop cultivation.

### (5) Soil microbial diversity and biological nitrogen fixation

This is an in-depth established research front in the field of applied ecology. The nitrogen cycle is closely related to agricultural production and the ecological environment. The application of nitrogen fertilizers increases crop yield. At the same time, fertilizer runoff disrupts the natural balance of nitrogen leading to global environmental problems. Numerous studies have shown that the natural nitrogen cycle is facilitated by microorganisms. Some bacteria can convert atmospheric nitrogen into ammonia by employing a process referred to as nitrogen fixation. Abundant in nature, nitrogen-fixing bacteria can be categorized as free-living, symbiotic and associative. Nitrification is a biological process in which ammonium nitrogen is used directly as a substrate, and it is a key step in the nitrogen cycle. Nitrification is caused by bacteria and archaea, and it is generally performed symbiotically by ammonia and nitrite oxidizers. Theoretical studies of biological nitrogen fixation have focused on the optimal conditions responsible for inducing the nodulation of non-legume crops and improving the efficiency of symbiotic nitrogen fixation. Some of the research areas include effective methods for inducing the formation of symbiotic nodules in key crops using rhizobium invasion, improving the efficiency of the symbiotic nodules of non-legume crops, and the path, the induction site, and the symbiotic mechanism of *Rhizobium* induced into non-legume host cells. The basic and applied research has focused primarily on developing new nitrogen-fixing plants, for example, by using biotechnology to transform nitrogen-fixing bacteria and existing crops to facilitate the formation of the symbiotic relationship between the new bacteria and the new crops, thus improving their nitrogen-fixing efficiency.

### (6) Plant diversity and global biosecurity

This is an in-depth established research front in the field of applied ecology. Plant diversity includes species, genetic and ecological diversity. The analysis of the mechanisms behind biodiversity generation and the use of various scales to explain the factors that contribute to plant diversity patterns enable us to have a better understanding of the neutral and niche processes that are responsible for the coexistence of species, and helps to recognize potential threats to global biodiversity.

### (7) Heavy-metal pollution in soil and stress on crops

This is an in-depth established research front in the field of agricultural resources science. Heavy-metal pollution refers to environmental pollution caused by heavy metals or their compounds, and is primarily due to human factors such as mining, exhaust emissions, sewage irrigation and products with excessive heavy-metal content. Heavy metals are defined as metallic elements with a density exceeding 4.5 $g/cm^3$. The most common heavy metals include lead, cadmium, mercury, chromium, and the metalloid arsenic. Heavy-metal pollution directly affects agricultural production and food safety, thus endangering the human habitat, and it is one of the most serious ecological and environmental problems currently being faced globally. There are few visible signs of heavy-metal pollution in farming. However, heavy metals are highly toxic, and their chemical behavior and ecological effects are complex. They remain in soil for a long time, and are absorbed by crops and are transferred into the food chain, or migrate into water bodies and the atmosphere. Thus, heavy-metal pollution poses a significant threat to human survival and sustainable development. Given its damaging effect on the environment, food safety and agricultural development, heavy-metal pollution of farmlands has become an important research front in the areas of environmental science and other related fields. The effects of heavy metals on crops are mainly reflected in the crop growth and development process, the physiological and biochemical indices, as well as crop yield and quality. At present, there are two types of remediation techniques for heavy-metal contaminated soil. One is to directly remove the heavy-metal contaminated soil, while the other involves changing the form of the heavy metals in soil to reduce their activity, mobility, and bioavailability. Remediation methods can be categorized as physical, chemical, electrical and biological methods.

#### (8) Crop nutrition supply and agricultural sustainable development

This is an in-depth established research front in the field of crop science. In agriculture, soil is the basic means of production, and is the foundation of crop growth. The support of fertilizers is required to improve soil fertility. Therefore, ensuring a stable supply of soil fertilizers and improving the efficiency of their use is the key to realizing sustainable agricultural development. In addition, improving the distribution of soil fertilizers, preventing environmental pollution and arable land degradation, and meeting the nutritional requirements of crops through rational fertilization are essential for achieving green agricultural development. The composition of soil should be thoroughly tested before applying a specific fertilization treatment. For highly fertile soils, ensuring high productivity and the efficient recycling of nutrients are important areas of research.

#### (9) Mechanism of plant response to biotic and abiotic stress

This is a newly emerging research front in the field of agricultural resources science. The important research front diagram reveals two major areas of research: biotic and abiotic stress. Of these types, biotic stressors include insects (herbivory) and gray mold (fungus). The main research directions include defense-response, immune response, systemic acquired resistance, induced resistance and signal transduction. In the area of abiotic stress, the most commonly researched factors and fronts include drought, reactive oxygen species, high temperature, salt, oxidative stress and osmotic stress. The research involves content such as the role of abscisic, salicylic, and jasmonic acids in hormone signaling. It also includes major areas such as photosynthesis, stomatal conductance, and antioxidant enzyme systems. With respect to the methods employed, gene expression, transcription factors and transcriptional regulation remain the focus of this research. At the same time, modern "omics" fields, including transcriptomics and proteomics, are also important areas of research.

#### (10) Impact of forest structure on forest carbon cycle

This is an in-depth established research front in the field of forestry engineering. The carbon cycle has significant impacts at a global scale, especially climate warming. As forest ecosystems are a principal component of the terrestrial biosphere, changes in the carbon cycle of forest ecosystems have become an important research area in the field of global change. Research into the carbon cycle of forest ecosystem involves experimental methods such as biomass inventory, micrometeorology, the carbon-isotope technique, and geo-information science methods and modeling. Carbon sequestration and carbon-density distribution show large regional and spatiotemporal differences in forest vegetation and soil. In addition, the effect of environmental factors changes in different seasons. Therefore, research into carbon-cycle dynamics in forest ecosystems generally adopts a regional-scale transect carbon source/sink structure as the basis for the development of mainstream methodologies, including spatiotemporal quantification, acquisition of geo-information and modeling. Its goal is to quantitatively analyze the effect of human activity on the carbon budget of forest ecosystems, and to investigate the changes in the carbon cycle in these systems under global climate change. These unique carbon-cycle models for forest ecosystems have helped to broaden the application of modern science and technology, in areas such as computer technology and remote sensing, in the field of forest ecology.

## 1.2 Interpretations for three key engineering research fronts

### 1.2.1 Crop breeding by molecular design

The concept of molecular breeding was first proposed in 2003 by the Dutch scientists Peleman and van der Voort. The rapid development of the whole-genome sequencing technology and the significant progress in research on plant functional genomics have made it possible to conduct molecular design and breeding of crop cultivars at the whole-genome level, thus setting the direction of future development of crop-breeding technology. At the core of molecular breeding is the understanding of key genes, which control important agronomic traits, and their regulatory networks. Biotechnology and other methods are used to acquire or develop elite germplasm resources for use as components of molecular design. The appropriate design components are selected based on the breeding objectives, and are assembled using system-biology methods to cultivate new crop varieties. Compared with standard breeding, molecular-design breeding allows for the precise regulation of agronomic traits at the genetic level, and solves the problem of linkage drag. In addition, it shortens the breeding cycle, thus greatly increasing the breeding efficiency. Compared with molecular marker-assisted breeding, molecular-design breeding is more precise and offers more control. At present, a new generation of genomic-selection breeding technologies, such as zinc-finger nucleases, transcription activator-like effector nucleases (TALENs), CRISPR/Cas9, and oligonucleotide-directed mutagenesis, are being refined. These technologies are expected to be the core of future molecular-design breeding. Molecular-design breeding consists of the following three main steps. (1) Researching the target-trait genes and the relationship between genes, including the genetic population structure, polymorphic marker screening, genetic linkage map construction, and phenotypic and genetic analysis of quantitative traits. (2) Designing the target genotype based on the breeding objectives, under various ecological environment conditions. This step involves using the genetic information of important breeding traits (such as chromosome location and genetic effects of genes, gene-to-trait expression pathways and biochemical networks, gene-gene interaction, the interaction between the genes, and the genetic background and the environment) that have already been identified to simulate the phenotypes of various possible genotypes, so that the genotypes that satisfy specific breeding objectives can be selected. (3) Formulation of specific breeding programs. At present, many obstacles need to be overcome to achieve the full benefits of molecular-design breeding. For example, there is a need for a more accurate analysis of the highly intricate genetic pathways. In addition, a high throughput and accurate identification of crop phenotypic traits are required.

An analysis of relevant academic papers is presented below. According to the table of distribution by country (Table 1.2.1), the USA contributed the majority of core papers, accounting for about 39% of a total of 27 papers, with the citation rate exceeding 50%. In addition, Australia, Germany and France also had a relatively high number of core papers. In terms of research institutions (Table 1.2.2), Cornell University (USA) and ICRISAT were the main contributors. It is evident from the collaboration diagram (Figure 1.2.1) that there was close collaboration between the USA and France. Also, ICRISAT in India and CIMMYT in Mexico also cooperated frequently (Figure 1.2.2). With only five papers published, the Chinese Academy of Sciences had a relatively small number of core papers and frequently cited papers (Figure 1.2.2). The USA, China and Australia had the highest number of cited core papers (Table 1.2.3). In addition, the Agricultural Research Service, US Department of Agriculture had the highest output, accounting for about 22% of the total (Table 1.2.4).

Table 1.2.1 Countries or regions with the greatest output of core papers on the “crop breeding by molecular design”

| No. | Country/Region | Core papers | Percentage of core papers | Citations | Percentage of citations | Citations per paper |
|---|---|---|---|---|---|---|
| 1 | USA | 27 | 38.57% | 2 897 | 49.70% | 107.30 |
| 2 | Australia | 15 | 21.43% | 1 233 | 21.15% | 82.20 |
| 3 | Germany | 12 | 17.14% | 1 159 | 19.88% | 96.58 |
| 4 | France | 12 | 17.14% | 706 | 12.11% | 58.83 |
| 5 | China | 10 | 14.29% | 1 067 | 18.31% | 106.70 |
| 6 | India | 10 | 14.29% | 1 055 | 18.10% | 105.50 |
| 7 | Mexico | 10 | 14.29% | 1 178 | 20.21% | 117.80 |
| 8 | Japan | 7 | 10.00% | 333 | 5.71% | 47.57 |
| 9 | Spain | 5 | 7.14% | 857 | 14.70% | 171.40 |
| 10 | Canada | 4 | 5.71% | 624 | 10.71% | 156.00 |

An in-depth analysis of supporting data revealed that the highly cited representative paper entitled “A high-density SNP genotyping array for rice biology and molecular breeding” published in 2014 in *Molecular Plant* was cited 68

Table 1.2.2 Institutions with the greatest output of core papers on the “crop breeding by molecular design”

| No. | Institution | Core papers | Percentage of core papers | Citations | Percentage of citations | Citations per paper |
|---|---|---|---|---|---|---|
| 1 | Cornell Univ | 10 | 14.29% | 1 422 | 24.40% | 142.20 |
| 2 | Int Crops Res Inst Semi Arid Trop | 9 | 12.86% | 1 001 | 17.17% | 111.22 |
| 3 | Int Maize & Wheat Improvement Ctr | 9 | 12.86% | 1 077 | 18.48% | 119.67 |
| 4 | USDA Agr Res Service | 7 | 10.00% | 977 | 16.76% | 139.57 |
| 5 | Univ Western Australia | 6 | 8.57% | 628 | 10.77% | 104.67 |
| 6 | Chinese Acad Agr Sci | 5 | 7.14% | 317 | 5.44% | 63.40 |
| 7 | Kansas State Univ | 3 | 4.29% | 365 | 6.26% | 121.67 |
| 8 | Donald Danforth Plant Sci Ctr | 3 | 4.29% | 261 | 4.48% | 87.00 |
| 9 | Leibniz Inst Plant Genet & Crop Plant Res | 3 | 4.29% | 221 | 3.79% | 73.67 |
| 10 | Limagrain Europe | 3 | 4.29% | 170 | 2.92% | 56.67 |

Table 1.2.3 Countries or regions with the greatest output of citing papers on the “crop breeding by molecular design”

| No. | Country/Region | Citing papers | Percentage of citing papers | Mean year |
|---|---|---|---|---|
| 1 | USA | 1 393 | 28.72% | 2015.81 |
| 2 | China | 838 | 17.28% | 2016.18 |
| 3 | Australia | 543 | 11.20% | 2015.71 |
| 4 | India | 444 | 9.15% | 2015.78 |
| 5 | Germany | 429 | 8.85% | 2015.60 |
| 6 | France | 324 | 6.68% | 2015.65 |
| 7 | Canada | 258 | 5.32% | 2015.67 |
| 8 | UK | 252 | 5.20% | 2015.97 |
| 9 | Brazil | 200 | 4.12% | 2015.84 |
| 10 | Mexico | 169 | 3.48% | 2015.66 |

Table 1.2.4 Institutions with the greatest output of citing papers on the “crop breeding by molecular design”

| No. | Institution | Citing papers | Percentage of citing papers | Mean year |
|---|---|---|---|---|
| 1 | USDA Agr Res Service | 313 | 20.85% | 2015.89 |
| 2 | Int Crops Res Inst Semi Arid Trop | 164 | 10.93% | 2015.56 |
| 3 | Cornell Univ | 155 | 10.33% | 2015.45 |
| 4 | Int Maize & Wheat Improvement Ctr | 143 | 9.53% | 2015.73 |
| 5 | Chinese Acad Sci | 137 | 9.13% | 2016.20 |
| 6 | Ins Nat Rec Agr | 134 | 8.93% | 2015.44 |
| 7 | Chinese Acad Agr Sci | 127 | 8.46% | 2016.19 |
| 8 | Univ Western Australia | 113 | 7.53% | 2016.04 |
| 9 | Univ Queensland | 109 | 7.26% | 2015.67 |
| 10 | Kansas State Univ | 106 | 7.06% | 2015.75 |


Figure 1.2.1 Collaboration network among major countries or regions in the engineering research front of "crop breeding by molecular design"

times. One of the most important papers was "crop breeding chips and genotyping platforms: progress, challenges, and perspectives" published in 2017 in *Molecular Plant*. The most important research institutions included the Chinese Academy of Agricultural Sciences, ICRISAT and Cornell University. A high-frequency keyword analysis revealed that genomic selection, SNP and QTL were the main focuses of scientific research.

### 1.2.2 CRISPR/Cas9 genome editing in agricultural biotechnology

The emergence of genome-editing technology has led to a new global-scale trend in research. In 2012, it was listed as one of the top 10 scientific breakthroughs in the *Science*, and in 2014, it was selected by *Nature Methods* as one of the top 10 most influential methods in biological research over the previous decade. Genome-editing technology involves the use of endonucleases to cleave DNA at specific sites, producing double-strand DNA breaks and thereby inducing DNA-damage repair. The result is a targeted gene modification. The use of this technology speeds up the breeding process, solving the problem of long generation-time encountered in standard crossbreeding. At the same time, because the artificial mutation efficiency increase changed the natural evolution of crops, the environmental and food-safety risks of the genome-edited plans also increased. Four generations of gene-editing tools have already been developed and improved: the ZFNs, TALENs, MGN (meganucleases) and CRISPR/Cas9 systems.

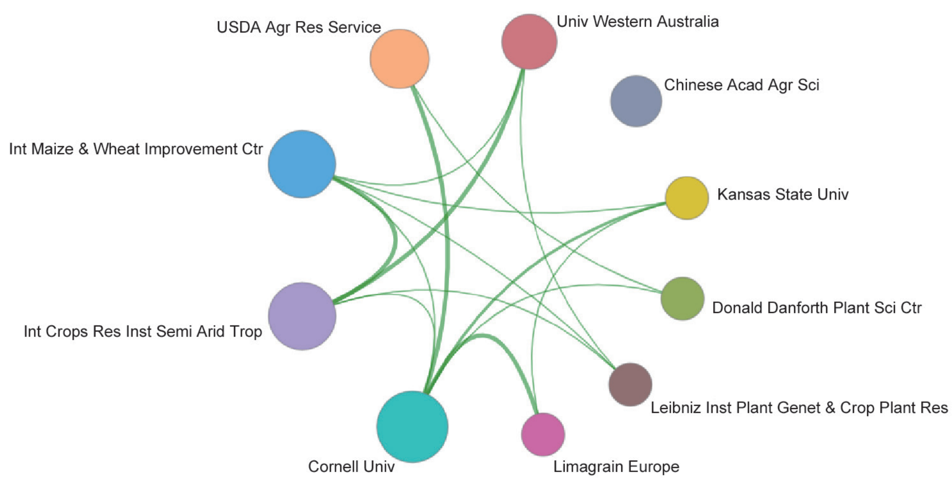


Figure 1.2.2 Collaboration network among major institutions in the engineering research front of "crop breeding by molecular design"

CRISPR/Cas9 is an accurate, highly efficient and versatile genome-editing tool. The basic principle of this editing tool is that the single-guide RNA (sgRNA) recognizes the three conserved nucleotides NGG (N being any nucleotide), called the protospacer adjacent motif (PAM) sequence, in the foreign genome. The sgRNA then guides the Cas9 protein to cleave the DNA strands upstream of the PAM. The double-stranded break in the DNA is repaired through non-homologous end joining, sometimes leading to insertions and deletions of base pairs. As a result, a frameshift mutation of the gene occurs, thus achieving a knockout of that gene. The CRISPR sgRNA requires a sequence of only 20 nucleotides to recognize the target PAM sequence, allowing the Cas9 monomeric protein to function. Compared with other types of gene-editing tools, the CRISPR/Cas9 system is easier to use. In addition, it has a higher knockout efficiency, allowing for more precise gene-editing and significantly reducing the off-target activity. The CRISPR/Cas9 has been widely used to edit important genes of animals and plants.

An analysis of relevant academic papers revealed the following. In terms of distribution by country (Table 1.2.5), the USA, China and Germany contributed the majority of core papers. The USA, China and Germany also had the highest number of citations. In terms of research institutions (Table 1.2.6), the Chinese Academy of Sciences ranked first with 11 core papers, but it had the third largest number of total citations, and was fifth in the average number of citations per paper. It is evident from the country collaboration diagram (Figure 1.2.3) that the USA cooperated most closely with China and Germany, having a leading role in research. The collaboration diagram of main research institutions (Figure 1.2.4) shows that the Chinese Academy of Sciences cooperated closely with the University of the Chinese Academy of Sciences, and had a degree of collaboration with the University of Minnesota (USA). The USA and China had the highest number of cited core papers. In addition, the proportions of cited core papers of these two countries far exceeded those of other countries or regions (Table 1.2.7). The combined number of cited core papers of the Chinese Academy of Sciences and the University of the Chinese

Table 1.2.5 Countries or regions with the greatest output of core papers on the “CRISPR/Cas9 genome editing in agricultural biotechnology”

| No. | Country/Region | Core papers | Percentage of core papers | Citations | Percentage of citations | Citations per paper |
|---|---|---|---|---|---|---|
| 1 | USA | 74 | 47.13% | 10 028 | 57.97% | 135.51 |
| 2 | China | 30 | 19.11% | 2514 | 14.53% | 83.80 |
| 3 | Germany | 21 | 13.38% | 2297 | 13.28% | 109.38 |
| 4 | UK | 17 | 10.83% | 930 | 5.38% | 54.71 |
| 5 | Japan | 12 | 7.64% | 872 | 5.04% | 72.67 |
| 6 | South Korea | 11 | 7.01% | 1351 | 7.81% | 122.82 |
| 7 | Netherlands | 8 | 5.10% | 1255 | 7.25% | 156.88 |
| 8 | Australia | 8 | 5.10% | 857 | 4.95% | 107.13 |
| 9 | Italy | 8 | 5.10% | 686 | 3.97% | 85.75 |
| 10 | France | 8 | 5.10% | 407 | 2.35% | 50.88 |

Table 1.2.6 Institutions with the greatest output of core papers on the “CRISPR/Cas9 genome editing in agricultural biotechnology”

| No. | Institution | Core papers | Percentage of core papers | Citations | Percentage of citations | Citations per paper |
|---|---|---|---|---|---|---|
| 1 | Chinese Acad Sci | 11 | 7.01% | 1706 | 9.86% | 155.09 |
| 2 | Univ Minnesota | 7 | 4.46% | 395 | 2.28% | 56.43 |
| 3 | Iowa State Univ | 6 | 3.82% | 458 | 2.65% | 76.33 |
| 4 | Massachusetts Ins Tech | 5 | 3.18% | 2274 | 13.15% | 454.80 |
| 5 | Univ Calif Berkeley | 5 | 3.18% | 1895 | 10.95% | 379.00 |
| 6 | Seoul Natl Univ | 5 | 3.18% | 1103 | 6.38% | 220.60 |
| 7 | Univ Calif Davis | 5 | 3.18% | 533 | 3.08% | 106.60 |
| 8 | Harvard Med Sch | 5 | 3.18% | 179 | 1.03% | 35.80 |
| 9 | Vanderbilt Univ | 4 | 2.55% | 634 | 3.67% | 158.50 |
| 10 | Univ Chinese Acad Sci | 4 | 2.55% | 408 | 2.36% | 102.00 |

Academy of Sciences approached 900, whereas the citation rate of the core papers exceeded 40% (Table 1.2.8).

An in-depth analysis of supporting data revealed that 40 papers were cited more than 200 times, of which eight papers were cited more than 500 times. The article "Genome engineering using the CRISPR/Cas9 system" published in 2013 in *Nature Protocols* was cited more than 1900 times. Also, the paper entitled "Development and applications of CRISPR/Cas9 for genome engineering" published in 2014 in *Cell* was cited nearly 1600 times. These two articles laid the foundation for the CRISPR/Cas9 system to become the leading gene-editing technology. At present, the CRISPR/Cas9 technology is widely applied in genomes of organisms such as humans, *Arabidopsis*, yeast, mice and fruit flies. Also, it has been


Figure 1.2.3 Collaboration network among major countries in the engineering research front of "CRISPR/Cas9 genome editing in agricultural biotechnology"

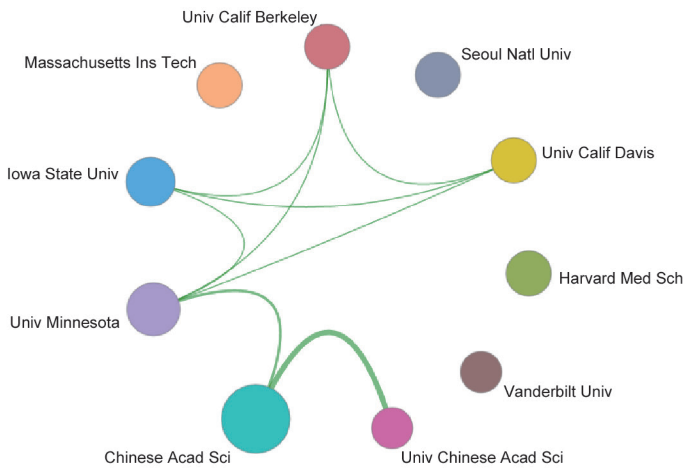


Figure 1.2.4 Collaboration network among major institutions in the engineering research front of "CRISPR/Cas9 genome editing in agricultural biotechnology"

Table 1.2.7 Countries or regions with the greatest output of citing papers on the "CRISPR/Cas9 genome editing in agricultural biotechnology"

| No. | Country/Region | Citing core papers | Percentage of citing papers | Mean year |
|---|---|---|---|---|
| 1 | USA | 4 318 | 36.55% | 2016.22 |
| 2 | China | 2 291 | 19.39% | 2016.45 |
| 3 | Germany | 1 050 | 8.89% | 2016.33 |
| 4 | UK | 878 | 7.43% | 2016.25 |
| 5 | Japan | 690 | 5.84% | 2016.10 |
| 6 | France | 621 | 5.26% | 2016.33 |
| 7 | Australia | 553 | 4.68% | 2016.26 |
| 8 | Netherlands | 506 | 4.28% | 2016.22 |
| 9 | Canada | 499 | 4.22% | 2016.41 |
| 10 | Italy | 408 | 3.45% | 2016.29 |

Table 1.2.8 Institutions with the greatest output of citing papers on the "CRISPR/Cas9 genome editing in agricultural biotechnology"

| No. | Institution | Citing core papers | Percentage of citing papers | Mean year |
|---|---|---|---|---|
| 1 | Chinese Acad Sci | 625 | 29.69% | 2016.20 |
| 2 | Univ Chinese Acad Sci | 251 | 11.92% | 2016.42 |
| 3 | Harvard Univ | 213 | 10.12% | 2015.58 |
| 4 | Univ Calif Berkeley | 173 | 8.22% | 2016.01 |
| 5 | Harvard Med Sch | 166 | 7.89% | 2016.90 |
| 6 | Massachusetts Ins Tech | 154 | 7.32% | 2015.98 |
| 7 | Chinese Acad Agr Sci | 149 | 7.08% | 2016.71 |
| 8 | Univ Calif San Diego | 125 | 5.94% | 2016.40 |
| 9 | Stanford Univ | 125 | 5.94% | 2016.34 |
| 10 | Univ Calif Davis | 124 | 5.89% | 2016.15 |

successfully used in the genomes of economically important animals, including cattle, pigs and sheep as well as important crops, such as wheat, sorghum, rice and maize, thus achieving targeted genome editing. The analysis of high-frequency words revealed that CRISPR/Cas9, TALENs, and microbial population were the front areas of scientific research.

### 1.2.3 Intelligent agricultural equipment

The development of intelligent agricultural equipment control technology focuses on the development and expansion of various information technologies, including sensors, communication systems, image-processing systems and computer vision. For this research front there are four major research areas. (1) Specialized sensors: research on new principles, methods, and technology for agricultural sensors; the theory and technology of multi-sensor information fusion and measurement; and agricultural sensor networks. (2) Agricultural bioinstruments: research and development of animal and plant bioinformation monitoring sensors and devices; precision breeding equipment and information technology products; and animal and plant microphysiological-information testing equipment. (3) Intelligent agricultural machinery: research on precise variable-rate control, navigation, and real-time operation-monitoring technologies. The development of agricultural intelligent equipment that supports precise farming operations. (4) Agricultural robots: research on bionic principles; design of fundamental components; optimization paths; intelligent control; and decision-support algorithms. The development of model robotic-systems for farming operations. Research on developments in 2017 revealed that most of the patents that are related to the present study came from China and the USA. China accounted for about 75% of all patents, while the USA accounted for less than 25%. However, the ratio of patent citations is just the opposite, indicating that despite having fewer patents, the USA had a significant influence in this area. In terms of contributing institutions, Hunter Industries (USA) and China Agricultural University were the major contributors to patents. Also, USA and Canadian institutions collaborated significantly. At present, while the existing equipment meets the agricultural needs at various levels, further research and development are required. Future research directions are expected to include digital design, simulation systems and testing platforms of intelligent equipment; agricultural sensors, agricultural robots and navigation control technology with microelectromechanical systems; and the integration of advanced information technology (such as the Internet of Things, big data, cloud computing and cloud services) into the design of intelligent agricultural equipment.

An analysis of relevant academic papers revealed the following. In terms of distribution by country (Table 1.2.9), the majority of core articles was contributed by China and the USA. Although the contribution of core papers from Spain was less than half that from China, it ranked first with respect to the number of cited papers. In terms of research institutions (Table 1.2.10), the distribution of core papers was relatively randomly distributed, with no particularly strong contributors.

The country collaboration diagram (Figure 1.2.5) reveals that there was frequent collaboration between the USA and China as well as the USA and India. In addition, Spain and Italy also collaborated closely. The institution collaboration diagram (Figure 1.2.6) shows that only the University of Sydney (Australia) and the University of São Paulo (Brazil) collaborated closely. China ranked first in terms of the number of core papers contributed in this research direction. However, it ranked only fifth in terms of the number of cited papers and its average citation rates also lagged behind those of other countries (Table 1.2.11). The Chinese Academy of Sciences was the largest contributor of cited core papers (Table 1.2.12).

An in-depth analysis of supporting data revealed that Chinese scientists produced more research papers on intelligent agricultural equipment than in other areas. In addition, the number of conference papers was also relatively high. A high-frequency keyword analysis revealed that unmanned aerial vehicle, system integration and precision farming were the fronts on interest by the scientific community in this field.

## 2 Engineering development fronts

### 2.1 Development trends in the top 10 engineering development fronts

The top 10 engineering development fronts assessed by the field of agricultural engineering research are classified into the following three categories.

Ground breaking development front: “utilization technology

Table 1.2.9 Countries or regions with the greatest output of core papers on the “intelligent agricultural equipment”

| No. | Country/Region | Core papers | Percentage of core papers | Citations | Percentage of citations | Citations per paper |
|---|---|---|---|---|---|---|
| 1 | China | 85 | 17.31% | 185 | 8.36% | 2.18 |
| 2 | USA | 64 | 13.03% | 274 | 12.38% | 4.28 |
| 3 | Spain | 43 | 8.76% | 386 | 17.44% | 8.98 |
| 4 | India | 40 | 8.15% | 26 | 1.17% | 0.65 |
| 5 | Germany | 35 | 7.13% | 188 | 8.50% | 5.37 |
| 6 | Japan | 24 | 4.89% | 22 | 0.99% | 0.92 |
| 7 | Italy | 23 | 4.68% | 293 | 13.24% | 12.74 |
| 8 | Australia | 21 | 4.28% | 136 | 6.15% | 6.48 |
| 9 | Israel | 18 | 3.67% | 163 | 7.37% | 9.06 |
| 10 | Netherlands | 15 | 3.06% | 223 | 10.08% | 14.87 |

Table 1.2.10 Institutions with the greatest output of core papers on the “intelligent agricultural equipment”

| No. | Institution | Number of core papers | Fraction of core papers | Total citation | Fraction of citations | Citations/paper |
|---|---|---|---|---|---|---|
| 1 | Ben Gurion Univ Negev | 9 | 1.83% | 96 | 4.34% | 10.67 |
| 2 | Univ Florida | 9 | 1.83% | 49 | 2.21% | 5.44 |
| 3 | Univ Tecn Federico Santa Maria | 8 | 1.63% | 36 | 1.63% | 4.50 |
| 4 | Univ Sydney | 8 | 1.63% | 29 | 1.31% | 3.63 |
| 5 | Consejo Superior Invest Cient | 7 | 1.43% | 158 | 7.14% | 22.57 |
| 6 | Nanjing Agr Univ | 7 | 1.43% | 42 | 1.90% | 6.00 |
| 7 | Agr Res Org | 7 | 1.43% | 41 | 1.85% | 5.86 |
| 8 | Hokkaido Univ | 7 | 1.43% | 10 | 0.45% | 1.43 |
| 9 | Univ Sao Paulo | 7 | 1.43% | 12 | 0.54% | 1.71 |
| 10 | Wageningen Univ | 6 | 1.22% | 87 | 3.93% | 14.50 |

Table 1.2.11 Countries or regions with the greatest output of citing papers on the "intelligent agricultural equipment"

| No. | Country/Region | Citing papers | Percentage of citing papers | Mean year |
|---|---|---|---|---|
| 1 | China | 309 | 24.72% | 2016.59 |
| 2 | USA | 252 | 20.16% | 2016.53 |
| 3 | Spain | 143 | 11.44% | 2016.33 |
| 4 | Australia | 117 | 9.36% | 2016.65 |
| 5 | Germany | 110 | 8.80% | 2016.28 |
| 6 | Italy | 84 | 6.72% | 2016.12 |
| 7 | UK | 66 | 5.28% | 2016.64 |
| 8 | France | 65 | 5.20% | 2016.46 |
| 9 | Canada | 52 | 4.16% | 2016.42 |
| 10 | Japan | 52 | 4.16% | 2016.50 |

Table 1.2.12 Institutes with the greatest output of citing papers on the "intelligent agricultural equipment"

| No. | Institutions | Citing papers | Percentage of citing papers | Mean year |
|---|---|---|---|---|
| 1 | Chinese Acad Sci | 29 | 14.87% | 2016.14 |
| 2 | Consejo Superior Invest Cient | 24 | 12.31% | 2016.29 |
| 3 | USDA Agr Res Service | 22 | 11.28% | 2016.45 |
| 4 | China Agr Univ | 22 | 11.28% | 2016.27 |
| 5 | Univ Florida | 18 | 9.23% | 2016.33 |
| 6 | Mendel Univ Brno | 17 | 8.72% | 2014.18 |
| 7 | Univ Tecn Federico Santa Maria | 17 | 8.72% | 2016.29 |
| 8 | Wageningen Univ | 16 | 8.21% | 2016.50 |
| 9 | Northwest A&F Univ | 15 | 7.69% | 2016.53 |
| 10 | Univ Sydney | 15 | 7.69% | 2016.53 |


Figure 1.2.5 Collaboration network among major countries in the engineering research front of "intelligent agricultural equipment"

of animal stem cell" of veterinary science, "crop transgenic technology" of crop science, and "animal models and animal genome editing" of veterinary science.

Newly emerging development fronts: "agricultural waste and biomass energy conversion" of agricultural engineering, "efficient utilization of solar energy in agricultural facilities" of agricultural engineering, and "development and utilization of intelligent agricultural machinery" of agricultural engineering.

In-depth established development fronts: "development of high-efficiency, low-toxicity disease control compounds for agricultural use" of plant protection science, "introduction of disease-resistant genes and utilization of new disease-resistant varieties" plant protection science, "forestry information database and ecosystem construction" of

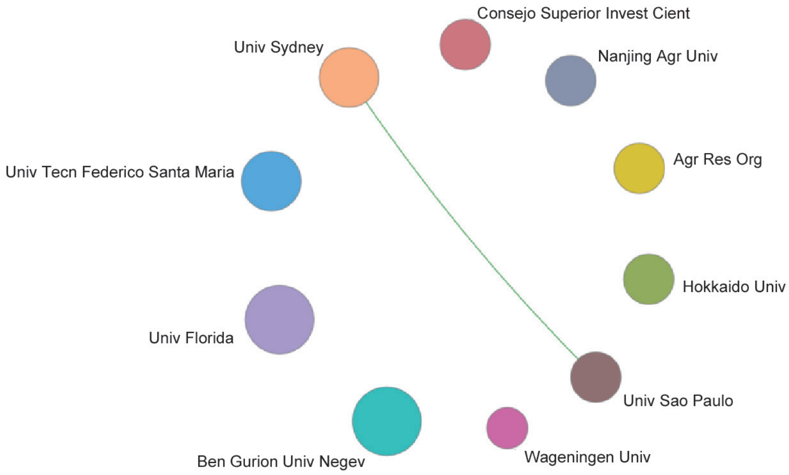


Figure 1.2.6 Collaboration network among major institutions in the engineering research front of "intelligent agricultural equipment"

forestry science, and "breeding of inbred lines and new hybrid varieties of crops" of crop science.

"Crop transgenic technology" had the highest number of patents, reaching 738. The average number of patents was around 310 patents. The article "animal models and animal genome editing" had the highest average number of patent citations, reaching about 33. Important research-area patents averaged 17 citations. A list of the highest average number of patents was published in May 2013 (Table 2.1.1). The average number of patents for all important research fronts showed a steadily decreasing trend year after year (Table 2.1.2).

Top 10 engineering development fronts are summarized below.

### (1) Utilization technology of animal stem cell

This technology is a ground breaking development front in the field of veterinary medical science. Animal stem cells are a type of self-renewing pluripotent cells. Under certain conditions, stem cells can be separated into different types of functional cells. Based on their developmental stage, stem cells can be divided into embryonic stem cells and somatic stem cells. Based on their differentiation potential, stem cells can be divided into three types: totipotent stem cells, pluripotent stem cells, and unipotent stem cells. Stem cells are a type of immature, undifferentiated cells that have the potential to regenerate various tissues and organs of the human body. In the medical field, these cells are known as all-

Table 2.1.1 Top 10 engineering development fronts in agriculture

| No. | Engineering development front | Published patents | Citations | Citations per patent | Mean year |
|---|---|---|---|---|---|
| 1 | Utilization technology of animal stem cell | 281 | 4 232 | 15.06 | 2013.91 |
| 2 | Agricultural waste and biomass energy conversion | 209 | 4 017 | 19.22 | 2012.86 |
| 3 | Crop transgenic technology | 738 | 14 216 | 19.26 | 2013.62 |
| 4 | Development of high-efficiency and low-toxic pesticide | 170 | 1 813 | 10.66 | 2013.29 |
| 5 | Animal model and animal genome editing | 135 | 4 549 | 33.70 | 2013.46 |
| 6 | Introduction of disease resistance gene and its utilization | 308 | 4 639 | 15.06 | 2013.40 |
| 7 | Efficient use of solar energy in agricultural facilities | 157 | 3 299 | 21.01 | 2012.78 |
| 8 | Development and utilization of intelligent agricultural machinery | 595 | 12 540 | 21.08 | 2013.64 |
| 9 | Forestry information database construction and ecosystem construction | 210 | 765 | 3.64 | 2013.89 |
| 10 | Crop inbred lines breeding and new hybrid varieties | 301 | 4 005 | 13.31 | 2013.45 |

Table 2.1.2 Annual number of core patents published for the top 10 engineering development fronts in agriculture

| No. | Engineering development front | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|
| 1 | Utilization technology of animal stem cell | 74 | 49 | 58 | 37 | 53 | 10 |
| 2 | Agricultural waste and biomass energy conversion | 102 | 56 | 35 | 12 | 3 | 1 |
| 3 | Crop transgenic technology | 187 | 185 | 173 | 115 | 73 | 5 |
| 4 | Development of high-efficiency and low-toxic pesticide | 58 | 46 | 32 | 27 | 7 | 0 |
| 5 | Animal model and animal genome editing | 37 | 33 | 40 | 19 | 3 | 3 |
| 6 | Introduction of disease resistance gene and its utilization | 108 | 77 | 55 | 39 | 18 | 11 |
| 7 | Efficient use of solar energy in agricultural facilities | 82 | 40 | 23 | 11 | 1 | 0 |
| 8 | Development and utilization of intelligent agricultural machinery | 155 | 140 | 124 | 124 | 45 | 7 |
| 9 | Forestry information database construction and ecosystem construction | 40 | 43 | 56 | 47 | 19 | 5 |
| 10 | Crop inbred lines breeding and new hybrid varieties | 84 | 90 | 66 | 34 | 23 | 4 |

purpose cells. Stem cells are widely used in the basic research of animal medicine and the animal disease treatment.

### (2) Agricultural waste and biomass energy conversion

This is a newly emerging development front in the field of agricultural engineering. High consumption and high production have been the long-term pattern of agricultural development. As a result, while the supply of agricultural products has been increasing, the quantity of agricultural byproducts and waste, such as crop straw and animal manure, has also increased rapidly. In addition, the improper use of agricultural waste has led to serious natural-resource and environmental problems. At present, the development of biomass energy is focused on five technologies: gasification, compressed fuel, combustion power-generation, ethanol production and biodiesel production. Among these, biomass gasification fuel and biomass compression molding are already mature technologies. In terms of biomass combustion power-generation, high-efficiency direct-fired power-generation is considered to be the most viable method of biomass utilization, and it is an important future direction of technological development.

### (3) Crop transgenic technology

This technology is a ground breaking development front in the field of crop science. Transgenic technology utilizes modern biotechnology to introduce and integrate the desired target genes, after their artificial separation and recombination, into the genome of an organism, thereby improving its original traits or introducing new traits. In addition to introducing foreign genes, transgenic technology can be used to alter the genetic characteristics of organisms in order to obtain desired traits, using such techniques as gene processing, knockout and shielding. The main processes of transgenic technology include the cloning of foreign genes, the construction of expression vectors, the establishment of genetic transformation systems, the selection of genetic transformants, the analysis of genetic stability and backcrossing.

### (4) Development of high-efficiency and low-toxic pesticide

This is an in-depth established development front in the field of plant protection science. With the removal of some of the highly toxic organophosphorus pesticides from the international market, the demand for environmentally-friendly pesticides has increased significantly. This has presented more opportunities for the development of new types of pesticides, and has generated more public interest as well as research and development investments. High-efficiency, low-risk pesticides have the following main characteristics: ① high activity against target organisms, low dosage per unit area; ② low toxicity to humans and animals; ③ safety for crops, no phytotoxicity; ④ environmentally friendly and biosafe (for example, low toxicity to fish, hummingbirds and silkworm); and ⑤ easy to degrade to nontoxic substances. Chemical pesticides kill natural pests, pollute the environment, and are harmful to humans. In addition, plant pests and diseases may develop resistance to chemical pesticides.

### (5) Animal models and animal genome editing

This technology is a ground breaking development front in the field of veterinary medical science. Animal disease models are used in experimental physiology, experimental pathology and experimental therapeutics (including screening of new drugs). Animal models of human diseases are animals and materials that are used to simulate human disease in biomedical science experiments. Genome-editing technologies can be used to precisely modify the targeted endogenous genes of organisms, thereby providing valuable tools in the field of biomedical research. With the rapid development of genomics and genome-editing technology as well as the wide application of microinjection technology and somatic cell cloning technology, strategies and methods of breeding by molecular writing have also been gradually developed. Molecular writing can be used to efficiently create and verify new genetic markers. It also allows for the directional breeding of new varieties through precise, molecular-level genome editing, not only removing the reproductive barriers that separate various taxa and allowing cross-species genetic transfers, but also enabling the insertion, deletion, and substitution of single nucleotides into individual genomes. As a result, more animal models can be developed.

### (6) Introduction of disease resistance gene and its utilization

This is an in-depth established development front in the field of plant protection science. Based on the conserved structure of their encoding protein, plant disease-resistance genes are divided into five or more classes: including NBS-LRR, eLRR-TM, eLRR-TM-pkinase and STK. Although the distribution of different genes varies at the cellular level, and the structures of the NBS, kinase and LRR domains vary between different types of genes, they are able to participate in the cell-defense against invading pathogens through various mechanisms. In addition, the pyramiding of multiple effective disease-resistance genes not only improves crop resistance, but also increases crop yield and quality. In particular, from the perspective of disease resistance, the prolonged repeated use of a single gene makes it prone to the loss of its disease resistance. Therefore, gene pyramiding can expand the resistance spectrum of genes, thus improving crop resistance.

### (7) Efficient use of solar energy in agricultural facilities

This is a newly emerging development front in the field of agricultural engineering. The photovoltaic (PV) solar energy greenhouse is a newly emerging type of agricultural facility that combines modern agricultural greenhouses with thin-film PV power-generation technology and LED lighting technology. This technology enables the utilization of farmlands for direct low-cost power-generation without affecting the growth of greenhouse crops. Solar-powered sprinkler irrigation units combine the PV solar power-generation technology with a sprinkler machine to transform current irrigation methods into mobile sprinkler irrigation. In addition to the highly uniform distribution of water and its associated energy savings, this technology also has a significant water-saving potential. In order to achieve the on-site consumption of PV energy, an intelligent micro-energy network based on time-shiftable agricultural load can be constructed for the solar greenhouse. The development of this low-carbon footprint agricultural technology will result in both economic and ecological benefits.

### (8) Development and utilization of intelligent agricultural machinery

This is a newly emerging development front in the field of agricultural engineering. Research in the area of intelligent agricultural machinery involves the use of precise variable-rate control technology, navigation technology and real-time operation-monitoring technology to develop intelligent agricultural equipment that supports precise farming operations. Intelligent agricultural machinery integrates advanced technologies, such as information and communication technology, computer network technology, and control and detection technology, which are essential for the rapid development of modern agriculture. Some of the development trends in this field include intelligent agricultural big-data platform establishment, connected agricultural-equipment operations, and agricultural robot and original farming-equipment technology development.

### (9) Forestry information database construction and ecosystem construction

This is an in-depth established development front in the field of forestry. Forest reserves form the constantly changing material base of forestry. To optimize forest structure and distribution, and to continuously improve the quality and quantity of forest resources, it is essential to improve the management of forest reserves and to use computer technology to manage the storage of quantitative forest resources data. Such a storage system comprises the forestry information database. The forestry information database includes existing forest information technologies such as the forestry resources survey-management system, the forest land-management system, the forest tenure-management system, and the comprehensive decision-support system. Integrating the existing forestry resources data and transforming current forestry management methods can strengthen resource supervision and work management, and can also improve forestry-related social services. Finally, with the associated scientific and technological advancements, the forestry information database should also be connected to geographic information systems, the remote-sensing information system and the forecasting model system to contribute in a more prominent way to the scientific management of forest resources and the construction of forest ecosystems.

#### (10) Crop inbred lines breeding and new hybrid varieties

This is an in-depth established development front in the field of crop science. The crop inbred line refers to the nearly identical offspring of a single plant after successive selfings. Crop inbreeding allows for the utilization of the effects of heterosis, which is an important approach that is employed to significantly increase crop yield, quality, stress resistance and adaptability. Basic research on heterosis includes: ① the use of germplasm resources to maximize the development and utilization of heterosis, ② an in-depth study of heterotic groups and their identification at the molecular level, ③ the screening of quantitative trait loci (QTL) for yield-related heterosis formation, and ④ suitable genetic populations for studying heterosis. Gene-expression profiling studies contribute to the understanding of the molecular mechanisms behind heterosis formation.

## 2.2 Interpretations for three key engineering development fronts

### 2.2.1 Utilization technology of animal stem cell

Of the many types of adult stem cells, hematopoietic stem cells (HSCs) are a type of stem cell that has been the subject of early studies on genetics, and are recognized to be effective in clinical applications. HSCs are self-renewing and pluripotent adult stem cells that have the potential to differentiate into various blood cells. Being the most primitive type of cells in the hematopoietic system, they are the source of all red blood cells, platelets and white blood cells (including granulocytes, monocytes and lymphocytes), sustaining the lifelong hematopoiesis of organisms. HSCs are found in microenvironments within the bone marrow. Therefore, the HSC functions are regulated by various internal and external factors. HSC transplantation is used not only to treat hematopoietic malignancies, but also to treat other diseases such as autoimmune and metabolic diseases. In addition, they are important in animal regenerative medicine.

For this development front, the majority of published patents are from the USA and China (Table 2.2.1). The USA accounted for two-thirds, occupying the leading position. In terms of core patent distribution by contributing institutions (Table 2.2.2), DuPont USA had the highest number of patents, whereas the China Agricultural University had a higher number of core patent citations. The country and region collaboration diagrams (Figure 2.2.1) indicate that the USA, Denmark and Switzerland cooperated extensively. The institution collaboration network diagram (Figure 2.2.2) indicates that BROD (Broad Inst. Inc.), MASI (Massachusetts Inst. Tech.), and HARD (Harvard College) had the closest collaboration.

### 2.2.2 Agricultural waste and biomass energy conversion

Biomass energy refers to a form of energy that comes from the conversion of solar energy into chemical energy by plants, and is stored in biomass. This type of energy comes directly or indirectly from the photosynthesis of green plants, and can be converted into conventional solid, liquid, or gaseous fuels. Biomass is an inexhaustible and renewable energy source, and is the only renewable source of carbon. At present, the development of biomass energy is focused on five technologies, namely gasification, compressed fuel, combustion power-generation, ethanol production, and biodiesel production. Among them, biomass gasification fuel and biomass compression molding are already mature technologies. In terms of biomass combustion power-generation, high-efficiency direct-fired power-generation is considered to be the most viable method of biomass utilization, which is an important future direction for potential technological development. However, the efficiency of forest-waste conversion into fuel ethanol is still low, remaining in the experimental stage. The development of ethanol production technology based on lignocellulose will be the front of future

Table 2.2.1 Countries or regions with the greatest output of core patents on the "utilization technology of animal stem cell"

| No. | Country/Region | Published patents | Percentage of published patents | Citations | Percentage of citations | Citations per patent |
|---|---|---|---|---|---|---|
| 1 | USA | 178 | 63.35% | 2 876 | 67.96% | 16.16 |
| 2 | China | 54 | 19.22% | 606 | 14.32% | 11.22 |
| 3 | Denmark | 13 | 4.63% | 223 | 5.27% | 17.15 |
| 4 | Netherlands | 11 | 3.91% | 180 | 4.25% | 16.36 |
| 5 | France | 9 | 3.20% | 188 | 4.44% | 20.89 |
| 6 | Japan | 9 | 3.20% | 98 | 2.32% | 10.89 |
| 7 | Canada | 5 | 1.78% | 69 | 1.63% | 13.80 |
| 8 | Germany | 5 | 1.78% | 121 | 2.86% | 24.20 |
| 9 | UK | 5 | 1.78% | 56 | 1.32% | 11.20 |
| 10 | Switzerland | 4 | 1.42% | 59 | 1.39% | 14.75 |

Table 2.2.2 Institutions with the greatest output of core patents on the "utilization technology of animal stem cell"

| No. | Institutions | Country | Published patents | Percentage of published patents | Citations | Percentage of citations | Citations per patent |
|---|---|---|---|---|---|---|---|
| 1 | DUPO | USA | 20 | 7.12% | 331 | 7.82% | 16.55 |
| 2 | MASI | USA | 16 | 5.69% | 421 | 9.95% | 26.31 |
| 3 | Broad Inst Inc | USA | 15 | 5.34% | 412 | 9.74% | 27.47 |
| 4 | HARD | USA | 12 | 4.27% | 268 | 6.33% | 22.33 |
| 5 | REGN | USA | 12 | 4.27% | 169 | 3.99% | 14.08 |
| 6 | STAM | Netherlands | 7 | 2.49% | 103 | 2.43% | 14.71 |
| 7 | CECT | France | 6 | 2.14% | 145 | 3.43% | 24.17 |
| 8 | Recombinetics Inc | USA | 6 | 2.14% | 99 | 2.34% | 16.50 |
| 9 | REGC | USA | 5 | 1.78% | 85 | 2.01% | 17.00 |
| 10 | STRD | USA | 5 | 1.78% | 88 | 2.08% | 17.60 |

DUPO: Dupont Nutrition Biosciences Aps; MASI: Massachusetts Inst. Technology; HARD: Harvard College; REGN: Regeneron Pharm Inc.; STAM: Dsm Intellectual Property Assets Manage; CECT: Cellectis; REGC: Univ. California; STRD: Univ. Leland Stanford Junior.


Figure 2.2.1 Collaboration network among major countries in the engineering development front of "utilization technology of animal stem cell"

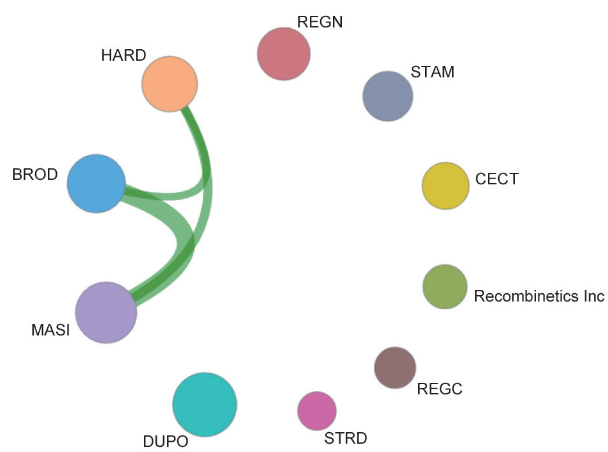


Figure 2.2.2 Collaboration network among major institutions in the engineering development front of "utilization technology of animal stem cell"

research and development. The technology for extracting biodiesel from tree seeds with high oil content remains in the exploration stage, and is still a long way from industrialization. This technology will become the front of future research and development.

The overwhelming majority of published patents in this development area came from the USA (Table 2.2.3), followed by China. The differences in the average number of citations between various countries were not significant. In terms of core patent distribution by contributing institutions (Table 2.2.4), the Butamax Advanced Biofuels LLC had the highest number of patents. The country and region collaboration diagram (Figure 2.2.3) indicates that the USA, the Netherlands, and the UK collaborated closely. It is evident from the institution collaboration diagram (Figure 2.2.4) that two companies in Suzhou, China had significant collaboration.

Table 2.2.3 Countries or regions with the greatest output of core patents on the “agricultural waste and biomass energy conversion”

| No. | Country/Region | Published patents | Percentage of published patents | Citations | Percentage of citations | Citations per patent |
|---|---|---|---|---|---|---|
| 1 | USA | 141 | 67.46% | 2816 | 70.10% | 19.97 |
| 2 | China | 32 | 15.31% | 531 | 13.22% | 16.59 |
| 3 | Netherlands | 9 | 4.31% | 166 | 4.13% | 18.44 |
| 4 | Canada | 8 | 3.83% | 167 | 4.16% | 20.88 |
| 5 | Germany | 5 | 2.39% | 99 | 2.46% | 19.80 |
| 6 | Denmark | 4 | 1.91% | 80 | 1.99% | 20.00 |
| 7 | UK | 4 | 1.91% | 116 | 2.89% | 29.00 |
| 8 | Australia | 3 | 1.44% | 77 | 1.92% | 25.67 |
| 9 | France | 3 | 1.44% | 37 | 0.92% | 12.33 |
| 10 | Japan | 3 | 1.44% | 52 | 1.29% | 17.33 |

Table 2.2.4 Institutions with the greatest output of core patents on the “agricultural waste and biomass energy conversion”

| No. | Institution | Country | Published patents | Percentage of published patents | Citations | Percentage of citations | Citations per patent |
|---|---|---|---|---|---|---|---|
| 1 | BUTA | USA | 14 | 6.70% | 350 | 8.71% | 25.00 |
| 2 | SHEL | USA | 8 | 3.83% | 216 | 5.38% | 27.00 |
| 3 | DUPO | USA | 7 | 3.35% | 141 | 3.51% | 20.14 |
| 4 | Suzhou Mingyue Pharm Technology Co Ltd | China | 7 | 3.35% | 109 | 2.71% | 15.57 |
| 5 | UNVO | USA | 6 | 2.87% | 114 | 2.84% | 19.00 |
| 6 | XYLE | USA | 6 | 2.87% | 116 | 2.89% | 19.33 |
| 7 | DOWC | USA | 5 | 2.39% | 75 | 1.87% | 15.00 |
| 8 | Suzhou Miracpharma Technology Co Ltd | China | 5 | 2.39% | 79 | 1.97% | 15.80 |
| 9 | ANGC | USA | 4 | 1.91% | 62 | 1.54% | 15.50 |
| 10 | Api Intellectual Property Holdings LLC | USA | 4 | 1.91% | 55 | 1.37% | 13.75 |

BUTA: Butamax Advanced Biofuels LLC; SHEL: Shell Int. Res. Mij Bv; DUPO: Dupont Nutrition Biosciences APS; UNVO: UOP LLC; XYLE: Xyleco Inc.; DOWC: Dow Global Technologies LLC; ANGC: Angus Chemical Company.

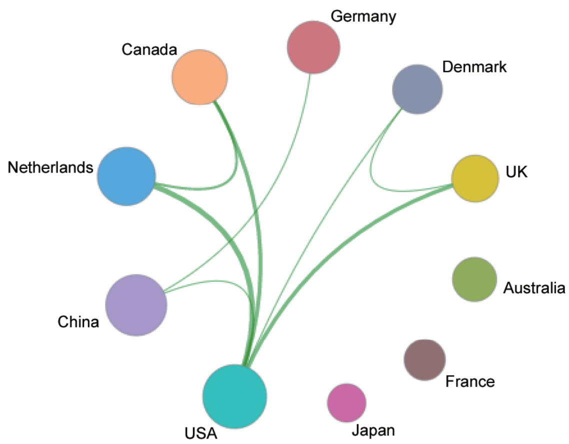


Figure 2.2.3 Collaboration network among major countries in the engineering development front of "agricultural waste and biomass energy conversion"

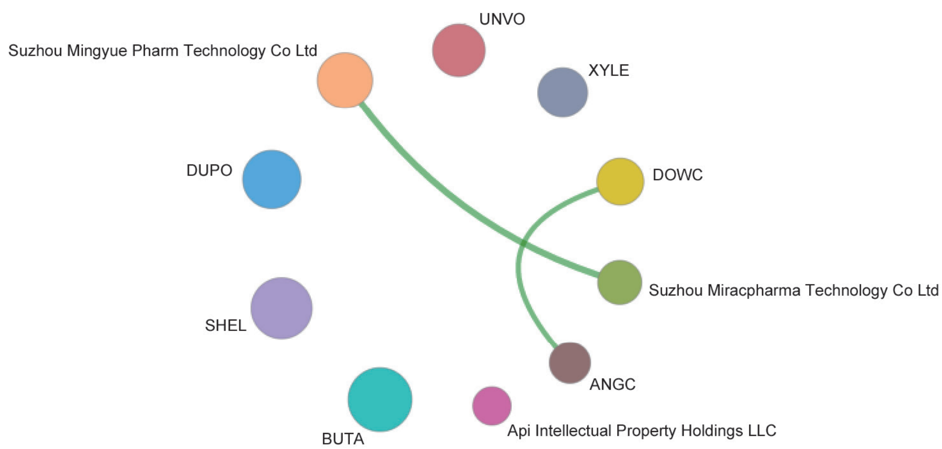


Figure 2.2.4 Collaboration network among major institutions in the engineering development front of "agricultural waste and biomass energy conversion"

### 2.2.3 Crop transgenic technology

Transgenic technology utilizes modern biotechnology to introduce and integrate the desired target genes, after their artificial separation and recombination, into the genome of an organism, thereby improving its original traits or introducing new traits. In addition to introducing foreign genes, transgenic technology can be used to alter the genetic characteristics of organisms in order to obtain desired traits, using techniques such as gene processing, knockout and shielding. The main processes of transgenic technology include the cloning of foreign genes, the construction of expression vectors, the establishment of genetic transformation systems, the selection of genetic transformants, the analysis of genetic stability and backcrossing.

The majority of published patents in this front area are from the USA and China. The USA had the highest proportion of published patents and a large number of average citations (Table 2.2.5). In terms of research institutions, the differences in the number of published core patents between various institutions decreased gradually (Table 2.2.6). The country and region collaboration diagram shows that the USA, Denmark, and Switzerland collaborated closely (Figure 2.2.5). The institution collaboration network diagram indicates that MASI, BROD, and HARD had the closest collaboration (Figure 2.2.6).

Table 2.2.5 Countries or regions with the greatest output of core patents on the "crop transgenic technology"

| No. | Country/Region | Published patents | Percentage of published patents | Citations | Percentage of citations | Citations per patent |
|---|---|---|---|---|---|---|
| 1 | USA | 462 | 62.60% | 9959 | 70.05% | 21.56 |
| 2 | China | 114 | 15.45% | 1285 | 9.04% | 11.27 |
| 3 | Denmark | 35 | 4.74% | 717 | 5.04% | 20.49 |
| 4 | Germany | 31 | 4.20% | 721 | 5.07% | 23.26 |
| 5 | Switzerland | 24 | 3.25% | 592 | 4.16% | 24.67 |
| 6 | UK | 24 | 3.25% | 334 | 2.35% | 13.92 |
| 7 | Netherlands | 24 | 3.25% | 456 | 3.21% | 19.00 |
| 8 | Japan | 19 | 2.57% | 307 | 2.16% | 16.16 |
| 9 | France | 17 | 2.30% | 325 | 2.29% | 19.12 |
| 10 | Canada | 16 | 2.17% | 202 | 1.42% | 12.63 |

Table 2.2.6 Institutions with the greatest output of core patents on the "crop transgenic technology"

| No. | Institution | Country | Published patents | Percentage of published patents | Citations | Percentage of citations | Citations per patent |
|---|---|---|---|---|---|---|---|
| 1 | HARD | USA | 35 | 4.74% | 940 | 6.61% | 26.86 |
| 2 | NOVO | Denmark | 34 | 4.61% | 736 | 5.18% | 21.65 |
| 3 | DUPO | USA | 32 | 4.34% | 500 | 3.52% | 15.63 |
| 4 | BROD | USA | 27 | 3.66% | 954 | 6.71% | 35.33 |
| 5 | MASI | USA | 27 | 3.66% | 959 | 6.75% | 35.52 |
| 6 | BUTA | USA | 26 | 3.52% | 688 | 4.84% | 26.46 |
| 7 | Moderna Therapeutics | USA | 14 | 1.90% | 599 | 4.21% | 42.79 |
| 8 | HOFF | Switzerland | 13 | 1.76% | 287 | 2.02% | 22.08 |
| 9 | STAM | Netherlands | 13 | 1.76% | 180 | 1.27% | 13.85 |
| 10 | CAGS | China | 12 | 1.63% | 149 | 1.05% | 12.42 |

HARD: Harvard College; NOVO: Novozymes AS; DUPO: Dupont Nutrition Biosciences APS; MASI: Massachusetts Inst Technol; BUTA: Butamax Advanced Biofuels LLC; BROD: Broad Inst. Inc.; HOFF: Hoffmann La Roche & Co Ag F; STAM: Dsm Intellectual Property Assets Manage; CAGS: Inst Crop Sci Chinese Acad Agric Sci.

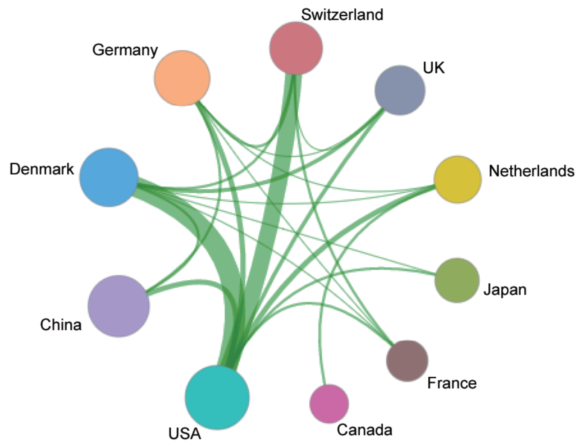


Figure 2.2.5 Collaboration network among major countries in the engineering development front of "crop transgenic technology"

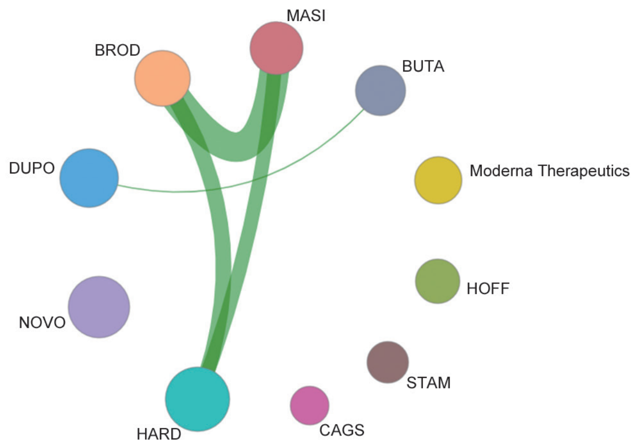


Figure 2.2.6 Collaboration network among major institutions in the engineering development front of “crop transgenic technology”

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### Acknowledgements

This report was completed with the support from the project “Strategic Consulting and Research of Global Engineering Fronts” in the Chinese Academy of Engineering, under the guidance and help of the project integration group. The data were processed and provided by *Clarivate Analytics* (Beijing). QIAN Xuhong, ZHENG Wenjiang, and MU Zhirui from the project integration group, and ZHOU Weixing, JI Jiuming, JIANG Zhiqiang, ZHANG Xiao, and other experts from the East China University of Science and Technology helped in chart plotting, etc. Further, we thank the members from the Standing Committee of Agriculture Faculty of Chinese Academy of Engineering, and the academicians and experts of the relevant fields in the selection of hotspots and fronts.