Science in India with Special Reference to Agriculture*

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Abstract

A brief survey of the glorious past of Indian science and technology, especially in the field of agriculture has been carried out to visualize the potential of India to carve out an equally glorious future. Pathways to ensure food security have been suggested.

Heritage of most Indians begins with the Vedas, which were compiled by the Aryan sages. Some of the Indology scholars of the 19th century, such as Max Müller, placed the age of Vedas around 1500 BC. The world accepted that date and continues believing it. Recent archaeological and other studies place the age of Rigveda, the oldest Veda, around 3700 BC. The Rigveda (Sontakke and Kashikar, 1983) has served and will serve as an encapsulated source of knowledge concerning almost all aspects of life in India, including the sciences. The Vedic thread can be seen in all the advancements that took place in India in the past. Vedic values continue to guide Indians even today. In this article, we have made an effort to very briefly summarize the developments in sciences from ancient through the modern times. We have placed relatively more emphasis on agriculture, as the food security for India will be a major issue in the future.

Overview of science and technology in ancient India

There is a general perception about India that its heritage is primarily religio-philosophical and there is hardly anything to mention about India's scientific and technological past. The reasons for this impression are due to the fact that references to science and technology are scattered in several different published works written in Sanskrit and Pali languages that are not currently in use. Moreover, the ancient knowledge is often in a very condensed form, which could be understood only by experts in those languages. In recent years, organizations like Vijnan Bharati (Mumbai) and Asian Agri-History Foundation (Hyderabad) have attempted to translate the ancient scientific literature into English. Information on scientific knowledge and technology in the fields of agriculture, architecture, astronomy, chemistry, mathematics, medicine, metallurgy, physics, shipping and navigation, textiles, numismatics, and design and layout is now widely available (Vijnan Bharati, 2002).

In developing science and technology, ancient Indian universities have played an important role. To name a few: Takshashila (Taxila) (800–540 BC) in the Northwest corner of the subcontinent (now near Rawalpindi, Pakistan) was the earliest. It provided education in a wide variety of subjects and used to host conferences in medicine and other fields that attracted scholars from Babylon, Syria, Arabia, Phoenicia, China, and Persia. This university had to face the brunt of attacks and invasions from Persians, Greeks, Parthians, Shakas, and Kushans. In c. 450 AD the Huns from Central Asia razed the institution.

The university at Varanasi (Banaras) has maintained a continued existence and reputation as a place of learning for over 3000 years. There were many other institutions of learning in ancient India and the name of Nalanda University, located in Bihar state of India, must be mentioned. Great scholars such as Chanakya, Nagarjuna, Buddhaghosha, Aryadeva, and Jyotipala taught at this university. It is said that there were 10,000 students and about 1500 teachers at Nalanda, thus having a student-teacher ratio of about 7:1. The University Library was so large that it was housed in three big buildings. This university also fell victim to the invading hordes of Bakhtyar Khilji in the 10th century. We will briefly focus on mathematics, medicine, and agriculture, which are some important branches of science and technology in ancient India.

Mathematics

Scientists of ancient India made a remarkable contribution to science of Mathematics. This is indicated in Table 1. Ancient India's greatest gifts to the world of mathematics are the concept of zero and the elegant place value system of numeration. Reference to the concept of zero is found in the works of the great Sanskrit grammarian Panini (500 BC) and Pingala (200 BC) who produced the science of Prosody. Early evidence to zero is also found in Bakshali manuscript (300–400 AD). The manuscript written on 70 leaves of birch bark was discovered in Bakshali village near Peshawar (now in Pakistan) in 1818 AD. It was translated into English by R Hoernal and is now kept in the Oxford University Library. The Decimal Place Value System, expressing all numbers by ten digits including zero and assigning to each an absolute value and place, is the most profound contribution of India to the world of mathematics, even to mankind. One of the greatest mathematicians, Pierre Laplace of France wrote: "It is India that gave us the ingenious method of expressing all numbers by ten symbols receiving a value of position, as well as an absolute value. We shall appreciate the grandeur of this achievement when we remember that it escaped the genius of Archimedes and Appolonius." Leonard Fibonacci Pisano introduced this system to European mathematics in 1202 AD. In Yajurveda, Ramayana, and other texts, separate names are given for numbers 1 to 10 power 53.

Table 1. Contributions of ancient Indian sages to Mathematics.

Period	Mathematical topics	Notable mathematicians
3000–1500 BC	Indus scale; length and weight; measurements and standardization	
1500–500 BC	Vedas, Vedantas, and Shulba sutras; word numerals; beginning of astronomy; arithmetical operations; Vedic geometry; Boudhayana's theorem, more widely known as Pythagoras theorem	Boudhayana, Apastamba, Katyayana
500–200 BC	Emergence of Jain mathematics; number theory; permutations and combinations; the binomial theorem Pingala's Chandah Sutra; Meru Prastara	
200 BC–400 AD	The Bakshali manuscript; rules of mathematical operations; first use of zero; simple algebra, unknown quantity representation; negative sign concept	
400–1200 AD	Best period of Indian mathematics; important mathematical works written such as Aryabhatiya, Panch Siddhantica, Bhashya, and Siddhanta Shiromani	Aryabhata, Bhaskara, Varahamihira, Mahabhashya, Brahmagupta, Sridhara, Mahavira, Bhaskaracharya

The Harappans developed standardization of weights and measures. Jain mathematicians (500 BC–100 AD) invented the perception to treat mathematics as an abstract discipline. The Sthanagana Sutra lists the topics studied by them, which included concept of geometry, fractions, equations, square, square root, cube and cube root. The concept of indices and logarithms, permutations and combinations was also introduced by Jain mathematicians (Bhagvati Sutra – 300 BC). Some great Indian mathematician-astronomers were:

- Aryabhata (476 AD) gave the value of 3.1416 for pie. He was the first in India to postulate that the earth is round, that it rotates on its axis creating day and night, that moon shines due to sunlight, and finally, that eclipses are due to shadows cast by earth and moon.
- Varahamihira (490 AD) is remembered for his revised version of Indian calendar. His contribution to mathematics was mainly in the area of trigonometry.
- Brahmagupta (598 AD) is said to be the founder of numerical analysis. He made several original contributions to algebra and trigonometry.
- Mahavira’s (815 AD) contributions were in the area of fractions, permutations and combinations, and the right-angled triangle.
- Sridharacharya’s (latter half of 10^{th} century) work was in the area of arithmetic, mensuration, and geometry. He was the first one to solve the quadratic equation in one variable.
- Bhaskaracharya (1114 AD) is known for the solution of the indeterminate equation of second order by the *Chakravala* method and his path-breaking work on cyclic quadrilaterals.

Science of Indian medicine (Ayurveda)

According to the legend, Brahma the creator of the universe propounded Ayurveda, an *upveda* (sub-Veda) of Atharvaveda; Daksha Prajapati learned Ayurveda from Brahma and passed it on to the celestial physician twins, the Ashwins. After handling by few more sages, the science of Indian medicine, the Ayurveda, was developed into three schools by the sages, Charaka, Sushruta, and Kashyapa. The celebrated *Samhitas* (compendiums) are known after these sages. Ayurveda has eight branches, namely general medicine, surgery, psychiatry, geriatrics, ophthalmology and ENT, toxicology, pediatrics, and sexual disorders. These medical practices were common in the Indus Valley Civilization (c. 3000 BC).

Ayurveda takes cognizance of individual’s constitution based on *tridosha* (three humors). This is the basic concept of Indian medicine. It helps the physicians as well as the common man. A person’s constitution is classified into seven categories: (1) *Vata*, (2) *Pitta*, (3) *Kapha*, (4) *Vata-Pitta*, (5) *Pitta-Kapha*, (6) *Vata-Kapha*, and (7) *Vata-Pitta-Kapha*. Each type of constitution results in specific ailments and can be treated accordingly. In the Indian medicine, the body is considered the vehicle of equilibrium, being the dwelling place of consciousness and comprising the sum of modifications of the five elements, i.e., sky, air, light, water, and earth. The anatomy deals with the structure of body, the soul (*atma*), the location, size, and shape of various parts of the body, and the mind. Anatomically, Ayurveda divides the human body into 19 parts (for detailed references see “Science and Technology in Ancient India” published by Vijnan Bharati, 2002). *Sharir-Kriya* (physiology) describes the biological and psychosomatic functioning of the living body and the biological components are divided into four categories: vital constituents, tissue components, biochemical transformers, and excretory materials, and have been described in great detail. In Ayurveda, the pulse of the patient is checked by the doctor with his bare hands, without any instruments, and several aspects of the patient’s medical conditions are inferred. The science of formulating medicinal preparations (pharmacology) and techniques to make medicaments from fresh herbs for internal and external use were very well advanced in ancient India. Plastic surgery was performed on regular basis. Rules for healthy living habits and diets were also well recognized. It is not surprising that Ayurveda still is a respected alternative medicine in India.

Agriculture in ancient India

Most of us grew up believing that Vedic Aryans from West Asia invaded the subcontinent around 1500 BC and destroyed the “Indus civilization” or the “Harappan civilization”. Aryans were then supposed to have colonized northern India and pushed out the original inhabitants (Dravidians) to southern India. However, with recent archaeological investigations, this theory of Aryan invasion has been seriously questioned. Information obtained thus far indicates that the Vedic civilization flourished in the northwestern (India and Pakistan) parts of the subcontinent more than 6000 years ago along the banks of the river Saraswati. This river dried up gradually over the years and the population living on its banks then slowly shifted westward towards Indus, giving rise to the Harappan civilization, and eastward towards and along the banks of the Ganges, and to the southern part of the subcontinent (Rajaram, 1993; Feuerstein et al., 1999).

Archaeological findings have revealed that rice was a domesticated crop grown along the banks of the Ganges in the sixth millennium BC. Later, it extended to other areas. Several species of winter cereals (barley, oats, and wheat) and legumes (lentil and chickpea) domesticated in Southwest Asia were grown in Northwest India before the sixth millennium BC. Archaeological research also revealed cultivation of several other crops 3000 to 6000 years ago. These include oilseeds such as sesame, linseed, safflower, mustards, and castor; legumes such as mung bean, black gram, horse gram, pigeonpea, field pea, grass pea (*khesari*), and fenugreek; fiber crops such as cotton; and fruits such as jujube, grapes, dates, jackfruit, mango, mulberry, and black plum. Animals, including livestock, sheep, goats, asses, dogs, pigs, and horses were also domesticated (Mehra, 1997).

Despite destruction of ancient libraries by invaders, some literature did survive and is available to us to this day. This literature includes the four Vedas, nine Brahmanas, Aranyakas, Sutra literature, Sushruta Samhita, Charaka Samhita, Upanishads, the epics Ramayana and Mahabharata, eighteen Puranas, Buddhist and Jain literature, and texts such as Krishi-Parashara, Kautilya’s Artha-sastra, Panini’s Ashtadhyahi, Sangam literature of Tamils, Manusmriti, Varahamihira’s Brhat Samhita, Amarkosha, Kashyapiya-Krishisukti, and Surapala’s Vrikshayurveda. This literature was most likely to have been composed between 6000 BC and 1000 AD. We find information related to biodiversity and agriculture (including animal husbandry) in these texts. Specifically, in the Puranas (300–750 AD ?) we find names of Shalihotra on horses and Palakapya on elephants, as experts in animal husbandry. For instance, Garudapurana is a text dealing with treatment of animal disorders while the classical work on the treatment of horses is Ashwashastra. One chapter in Agnipurana deals with the treatment of livestock and another on treatment of trees (Sensarma, 1989). The science of arbori-horticulture had developed well and has been documented in Surapala’s Vrikshayurveda (Sadhale, 1996). Forests were very important in ancient times. From the age of Vedas, protection of forests was emphasized for ecological balance (Nene and Sadhale, 1997). Kautilya in his Artha-sastra (321–296 BC) mentions that the superintendent of forests had to collect forest produce through the forest guards. He provides a long list of trees, varieties of bamboos, creepers, fibrous plants, drugs and poisons, skins of various animals, etc. that came under the purview of this officer (Shamasastry, 1961). According to Manu (Manusmriti, 2nd century BC), the preservation of wild animals was encouraged and hunting as a sport was regarded as detrimental to proper development of the character and personality of the ruler (Dwivedi, 1959).

There is more to learn from our ancient literature; for example, we learn about the biodiversity of flora. The four Vedas mention more than 75 species, Satapatha Bhrahmana mentions over 25 species, and Charaka Samhita (c. 300 BC) – an Ayurvedic (Indian medicine) treatise – mentions more than 320 plants. Sushruta (c. 400 BC) records over 750 medicinal plant species (Krishnamurthy, 1991). The oldest book, Rigveda (c. 3700 BC), mentions a large number of poisonous and non-poisonous, aquatic and terrestrial, and domestic and wild creatures and animals. Puranas mention about 500 species of plants.

Farm implements. Ancient literature of the subcontinent did not miss out on farm implements. Vedas describe a simple bullock-drawn wooden plow, both light and heavy, with an iron bar attached as a plowshare to open the soil. Krishi-Parashara (c. 400 BC) (Sadhale, 1999) gives details of the design of the plow with Sanskrit names for different parts. This basic design has hardly undergone any change over centuries. Even today the resource-poor farmers use a similar bullock-drawn plow. A bamboo stick of a specific size was used to measure land. Vedic literature and Krishi-Parashara also mention disc plow, seed drill, blade harrow (*bakhar*), wooden spike tooth harrow, plankers, axe, hoe, sickle, *supa* for winnowing, and a vessel to measure grain (*udara*). Pairs of bullocks used for plowing in ancient days varied from one to eight.

Forecast of annual monsoon rains. Since crop production depended almost entirely on seasonal monsoon rains, it was imperative that methods of predicting rainfall were developed. Indian knowledge base in mathematics, astronomy, and astrology was strong. Krishi-Parashara (c. 400 BC) and Brhat Samhita (Bhat, 1981) give, what today one could describe as, simple astrological models for predicting rains in a particular season. Parashara's main technique of forecasting rain was based on the positions of the Moon and the Sun in the sky. Varahamihira (505–587 AD) in his Brhat-Samhita considered lunar mansions in predicting seasonal rainfall. It is noteworthy that even today a large number of farmers in India, carry out farm operations based on the local variations of these old models.

Kautilya in Artha-sastra indicates primitive models for optimum rainfall for most crops. It is significant that the great poet, Kalidasa (c. 500 AD) in his immortal poem, Meghdoot, described the course of monsoon clouds from the Bay of Bengal through central and northern Indian plains to the Himalayas. It is remarkable that this accurate knowledge was obtained without the aid of modern instruments.

Types of lands. Rigveda identified productive and non-productive soils (Sharma, 1991). The Amarkosha (c. 400 BC) (Jha, 1999) described 12 types of lands in its chapter on *Bhumivargaha*, depending upon the fertility of the soil, irrigation, and physical characteristics. These were: *urvara* (fertile), *ushara* (barren), *maru* (desert), *aprahata* (fallow), *shadvala* (grassy), *pankikala* (muddy), *jalaprayah* (watery), *kachchaha* (land contiguous to water), *sharkara* (full of pebbles and pieces of limestone), *sharkaravati* (sandy), *nadimatruka* (land watered from a river), and *devamatruka* (rainfed). In the chapter on Vaisyavargaha, soils based on suitability for specific crops are mentioned. For example, *vraiheyam* (*vrihi* rice and corn), *shaleyam* (*kalama* rice), *yavyam* (awned barley), *yavakyam* (awnless barley), *tilyam* (sesame), *mashyam* (black gram), *maudginam* (mung bean), etc. are crops mentioned in relation to the soils. Sangam literature (200 BC to 100 AD) of Tamils in southern India provides information on soil types (Bedekar, 1993). For example, in Tholkappiyam, written by a poet named Tholkappier (200 BC), four types of land are mentioned. These are *mullai* (forest), *kuringi* (hills), *marudham* (cultivable), and *neithal* (coastal land). Surapala's Vrikshayurveda (c. 1000 AD) (Sadhale, 1996) mentions three types of land – *jangala* (arid), *anupa* (marshy), and *samanya* (ordinary) – further subdivided by color into black, white, pale, dark red, red, and yellow and by taste into sweet, sour, salty, pungent, bitter, and astringent. *Samanya* land was considered suitable for all kinds of trees. It is important to note that one of the most sustained land use practices, since the days of Kautilya, has been the use of river beds for raising cucurbits throughout India.

Manures. Importance of manures in obtaining high crop yields was fully appreciated in ancient India. In Krishi-Parashara, it is stated that crops grown without manure will not give yield, and a method of preparing manure from cowdung is described. Kautilya mentioned use of cowdung, animal bones, fishes, and milk as manure. In the Kural (1st century AD) (Aiyar, 1952), it is stated that manuring is more beneficial than plowing. Agnipurana (Gangadharan, 1986) recommends application of "excreta of sheep and goat and pulverized barley and sesame allowed to be soaked in meat and water for seven nights" to increase flowering and fruiting of trees. In Varahamihira's Brhat Samhita, growing of sesame to flowering stage and then incorporating it as green manure is recommended. Surapala (c. 1000 AD) describes the "ancient" practice of preparing liquid manure (*kunapa*) prepared by boiling a mixture of animal excreta, bone marrow, flesh, and dead fish in an iron pot and then adding to it sesame oilcake, honey, soaked black gram, and a little ghee (or clarified butter). No fixed quantities of materials were required to prepare *kunapa*. This liquid manure was mainly used in raising trees and shrubs.

Irrigation. Archaeological investigations in Inamgaon in Maharashtra, India (1300 BC), revealed a large mud embankment on a stone foundation for diverting floodwater from the Ghod River through a channel. Rigveda mentions irrigation of crops by river water through channels as well as irrigation from wells. Buddhist literature (500–300 BC) provides evidence of building small tanks for irrigation (Randhawa, 1980). Artha-sastra of Kautilya refers to sluice gates of tanks and mentions that "persons letting out the water of tanks at any other place other than their sluice-gate shall pay a fine of six *panas*; and persons who obstruct the flow of water from the sluice-gate of tanks shall also pay the same fine." It is further stated that "the water of a lower tank, excavated later on, shall not irrigate the field already irrigated by a higher tank and the natural flow of water from a higher to a lower tank shall not be stopped, unless the lower tank has ceased to be useful for three consecutive years." Costs were levied on irrigation water, regardless of the source.

Extensive tank irrigation systems were developed in Sri Lanka and southern India during the first two centuries of the Christian era. Availability of irrigation made it possible to extend cultivation of rice to large areas, and thus improve food security. Sri Lankan knowledge of tank irrigation technology was most advanced. They could build large tanks and control release of water by 3rd century BC (Brohier, 1934). For the maintenance of tanks in southern India, a committee of villagers called *eri-variyam* was appointed. The committee ensured repairs and desilting of tanks and distribution of water (Randhawa, 1980).

Irrigation from wells was practiced throughout India in ancient times. Bullocks pulled a leather bag with ropes to draw water from wells for irrigation. The so-called "Persian wheel" used for drawing water from wells was first developed in northern India prior to invasions by Turks.

Seed and sowing. Ancient scholars showed awareness of the importance of good seed; i.e., selection of the apparently healthy seed from a ripening crop, preserving it safely in storage, with or without treatments, and sowing the good seed, again with or without some treatment.

About 2000 years ago, Parashara (Sadhale, 1999) recommended (i) proper drying of seed, (ii) freedom from the seeds of weeds, (iii) visual seed uniformity, (iv) storing seeds in strong bags, and (v) storing seed where white ants would not have access and at a location where seed would not come in contact with substrates that would allow molds to grow such as cowshed wastes, damp spots, or leftover foods. Kautilya in Artha-sastra indicated that decision to sow seeds of specific crops should be taken on the basis of known rainfall patterns. He recommended that rice be sown first and mung bean and black gram later. He also suggested some seed treatments (e.g., cowdung, honey, and ghee) to ensure good germination. Manu (Dwivedi, 1959) mentioned that a professional farmer (the Vysya) must be able to determine the quality of seed. The most significant recommendation by Manu was severe punishment to a trader selling spurious seed. Varahamihira recommended pelleting of seed with flours of rice, black gram, and sesame and fumigating them with turmeric powder to ensure good germination. Surapala listed several botanicals such as seed treatment materials for shrubs and trees. Even today cowdung, suggested by Kautilya in the 4th century BC, is used for treating cotton and some other seeds by a large number of farmers (Nene, 1999).

The art of sowing rice seed in small areas, i.e., in nurseries, and transplanting of the seedlings is not a recent practice. It was first perfected in the deltas of Godavari and Krishna rivers in the 1st century AD (Randhawa, 1980).

Pests and their management. One of the earliest references to birds as pests is found in Rigveda. In the Kallavagga, Buddha pointed out when a disease called ‘mildew’ attacked a rice field, the latter would not produce grain. Likewise, sugarcane would be adversely affected if a disease called ‘blight’ affected it. Parashara (Randhawa, 1980) listed white ants and a number of other pests such as the *gandhi* bug and stem borer of rice. Parashara used the word “disease” in Sanskrit (*vyadhi*) to differentiate from visible pests. He even listed goats, wild boars, pigs, deer, buffaloes, parrots, and sparrows as pests. However, no remedies except chanting of a mantra to ward off pests were indicated. Agnipurana states that if fruits were destroyed, a paste of horse gram, black gram, mung bean, barley, and sesame should be applied after sprinkling the affected areas with cold water. In a later period, Varahamihira wrote a chapter on treatment of trees. He mentioned that trees are vulnerable to disease when exposed to cold weather, strong winds, and hot sun; consequently, their leaves become pale white, sprouts scanty and sickly, branches dry, and their sap oozes out. It seems Varahamihira laid the foundation of classifying tree diseases based on humors such as *vata*, *pitta*, and *kapha,* which were formalized in later centuries in Surapala’s Vrikshayurveda. Varahamihira describes cleaning of “ulcers” on trees and treating those with application of paste of *vidanga* (*Embelia ribes*), ghee, and silt. Premature destruction of fruits of a tree was to be controlled by application of water and milk (boiled and subsequently cooled) with powder of seeds, as mentioned in Agnipurana.

Surapala’s Vrikshayurveda, which deals with arbori-horticulture, gives considerable information on topics such as importance of trees, soil types, classification of plants, seed, sowing, planting, plant protection recipes, nourishment, types of gardens, locating groundwater, and bio-indicators for suitability or otherwise for raising crops and animals. Surapala gave description of disease symptoms associated with the three humors, *vata*, *pitta,* and *kapha*. In addition, he described disorders caused by excessive heat and wind, fire, lightning, drought stress, physical injury, ants (and other insects ?), excess water, bird damage, and possibly phanerogamic parasites. For treatment of disorders, he suggested use of a number of botanicals (many of which have antimicrobial properties) including mustard paste and milk. It is interesting to note that Surapala’s reference is largely to those plant species, which originated in the Indian subcontinent, confirming thereby that plant introduction had occurred to a very limited extent. He described a method of dwarfing trees in situ to create the “bonsai” effect.

Horticulture and arboriculture. Excavations at Harappa have indicated that people were familiar with date palm, pomegranate, lemon, melon, and possibly coconut. Emperor Ashoka (274–237 BC) encouraged arbori-horticulture (Randhawa, 1980). Commonly grown fruit trees were plantain, mango, jackfruit, and grapes. The Sangam literature (Bedekar, 1993) refers to jackfruit, coconut, date palm, areca nut, plantain, and tamarind. Agnipurana (Gangadharan, 1986) mentions many trees; it has a separate chapter on horticulture, which formed the base of treatises that followed. Varahamihira wrote a chapter on “treatment of trees” in his Brhat Samhita. One of the highlights of Varahamihira’s writing (Bhat, 1981) is specific reference on grafting to be done on trees such as jackfruit, plantain, *jambu* (black plum), *kapittaha* (wood apple), lemon, and pomegranate. A method of grafting described was what is known today as “wedge grafting” (Bhat, 1981).

Surapala’s Vrikshayurveda provides excellent information on arbori-horticulture in the northern part of the Indian subcontinent. The text mentions 170 species of plants including trees, shrubs, and a few herbs and deals systematically with raising of orchards; procuring, preserving and treating seeds and planting materials; selection of land; preparation of pits for planting; methods of irrigation and ways to locate groundwater; nourishment and fertilizers; disorders of plants and their protection; laying out gardens and orchards; and growing unusual trees (Sadhale, 1996).

Woodland gardening was a developed art. Layouts included designs such as *mandapa* (canopy), *nandyavarta* (quandrangle with an opening to the west), *swastika* (design of religious significance to Hindus), *chaturasra* (square), *sarvatobhadra* (a square enclosing a circle), *vithi* (line), *nikunja* (arbor), and *punjaka* (cluster). The text recommends layouts for the “pleasure gardens” (Sadhale, 1996).

Amarkosha mentions gardens such as *griharamah* (house garden), *vrikshavatika* (garden of ministers or prostitutes), *aakrida* (royal garden), and *pramadavanam* (garden for harem) (Jha, 1999).

Cattle management. Right from Vedic times, owning cattle meant possessing wealth. Rigveda is replete with references to cattle and their management (Nene and Sadhale, 1997). References can be found on grazing of livestock, provision of succulent green fodder and water to drink from clean ponds, and livestock barns. Dogs were used to manage herds of cows and in recovering stolen cows. Killing of cows was discouraged though Vedic people had no objection to eating beef. In the Vedic period, cows acquired sacredness and Buddha protested against cow killing. That finally led to total ban on cow slaughter in that period.

In Krishi-Parashara (c. 400 BC), a description of a cattle shed is found. Cleanliness of the shed was emphasized. To protect animals from diseases, cattle sheds were regularly fumigated with dried plant products that contained volatile compounds (Bedekar, 1993).

Several texts indicate treatments for curing livestock diseases such as those affecting the horns, teeth, buccal cavity, and human diseases/disorders such as sore-throat, carditis, lumbago, rheumatism, atrophy of muscles, and acute dysentery. Plasters were used to treat broken bones. Many other treatments were prescribed (Randhawa, 1980).

The Artha-sastra mentions a government officer called the superintendent of cattle whose exclusive duty was to supervise livestock in the country, keep a census of livestock, and see that they were properly reared. Livestock was classified as calves, tame steers, draft oxen, bulls that were to be trained to yoke, stud bulls, livestock reared for meat, buffaloes and draft buffaloes, female calves, heifers, pregnant cows, milch kine, barren livestock (either cows or buffaloes), and calves, that were a month or two old as well as those that were still younger and branded them all along with those livestock which had remained unclaimed for a month or two, and registered the branded marks, natural marks, and color (Shamasastry, 1961).

The Artha-sastra directed that all cattle be supplied with abundant fodder and water and gives an elaborate description of ration that a bull, cow, or buffalo should be supplied with. Maintenance of pastures around villages was encouraged. Manu presented that “on all sides of a village, a space of 100 *dhanus* or three *samya* throws (in breadth) shall be reserved for pasture." Fodder crops were cultivated and processed into silage – an old process in the Indian subcontinent as the word *suyavasa* in the Rigveda indicates. Cultivators also provided hay for their stock.

In Agnipurana, kings were encouraged to preserve the breed of the cattle in the country.

Fishing. Rigveda makes a general mention to fishes, but not as an item of food. Yajurveda mentions capturing fish by sedating them in a pond by treating the water with the bark of some trees. The fish culture or pisciculture originated in China almost 2500 years ago. Manusmriti mentions two fishes, *rohu* and *pathen*, suitable for food. In Surapala's Vrikshayurveda (c.1000 AD) two kinds of fish, *saphari* (a tiny shining fish) and *rohita* are mentioned. It is believed that fish culture came to Bengal from China, via Myanmar or Thailand. The Chalukya king Someshwara Deva (1127 AD) described methods of fattening fish and cited 34 kinds of fishes (Randhawa, 1980).

Honey. Honey was an important commodity in ancient times. Honey has been mentioned in Rigveda (Nene and Sadhale, 1997). It was an important item in food and medicine. The demand for honey was adequately met from natural hives until recently.

Support to agriculture. Agriculture in India was almost always supported by the multitudes of rulers because the sages impressed upon these rulers that prosperous agriculture was the base of strong kingdoms/empires. The tradition had been to impose minimal tax on farmers, rarely exceeding one-sixth of the produce. A couple of examples from the epics Ramayana and Mahabharata will illustrate the point. In Ramayana, Rama asks his brother Bharata in Chitrakoot, "Dear Bharata, have you ensured that all those engaged in agriculture and animal husbandry receive your special care and attention?" In Mahabharata, the grand old man, Bhishma, advises King Yudhishthira in "Shantiparva": "Agriculture, animal husbandry and trade are the very life of people. Have you ensured that the cultivators are not forced to deserting the country because of the exaction imposed by you? It is indeed the cultivators who carry the burden of the king on their shoulders and also provide sustenance to all others." Do we recognize this today? We probably need to continuously remind ourselves the wisdom of our ancestors.

Perception of India's science and technology

As discussed in the previous section, during the era from Aryabhata to Bhaskara (5^{th} to 12^{th} centuries AD) India enjoyed a state of science that was advanced compared to that in Arabia or Europe. Scholars like Al-Biruni visited India to study Sanskrit so that they could translate the Indian works like that of Brahmagupta and others into Arabic. Europe during the Dark Ages had nothing comparable to offer. The interesting question therefore is: Why India could not maintain its momentum in science?

There are various reasons for this. Rote learning practices were followed during ancient and medieval India. Knowledge of Vedas was passed down from one generation to next through oral tradition. So the teacher would have learned them by heart as a student and would pass them on to his disciples, along with commentaries, when he opened his own school. This method of teaching had limitations in stimulating original thinking (Narlikar, 2003). The other obvious reason is repeated invasions form West Asia that led to destruction of institutions and libraries after 1000 AD, followed by the Mogul and European colonization. Another reason was limited patronage to science during 10^{th} through 18^{th} century, during which India did not receive the same level of patronage to science as for literature, arts, and music. Poets such as the great Kalidasa flourished because of royal patronage. Later in the Mogul era, Emperor Akbar's court boasted of one of the greatest musicians, Tansen. There were many artists in the courts of Rajput kings and the Mogul emperors, but very few scientists. Moreover, the social structure also contributed to lack of drive to innovate and create. The caste system with its four major divisions placed the thinkers, teachers, and priests at the apex, followed by the rulers and warriors, then the farmers and traders and finally those who provided service. This stratification, though was done to have an orderly society, deprived a large section of people of education. The result of all these developments was that existing knowledge in science became unavailable to later generations. After the British consolidated their hold on India, the Indian educated section started looking up to Europe for scientific information. New discoveries, especially in medical sciences and chemistry, with the availability of antibiotics, vaccines for small pox, cholera, etc. also led people to reduce faith in ancient science of medicine.

Some of the most significant highlights of science in the 20th century pre-independent India are:

- Srinivasa Ramanujan's work on highly composite numbers (numbers with a large number of factors) started a whole new line of investigations in the theory of such numbers.
- Megha Nath Saha's ionization equation (c. 1920), opened the door to stellar astrophysics.
- S N Bose's work on particle statistics (c. 1922) clarified the behavior of photons (the particles of light in an enclosure) and opened the door to new ideas on statistics of microsystems that obey the rules of quantum theory.
- C V Raman's discovery that molecules scatter light (c. 1928) became known as the Raman effect. It is used to study the internal structure of molecules.
- G N Ramachandran's work in biology; he is considered one of the founders of the rapidly developing molecular biophysics.
- J C Bose's basic work in plant physiology.
- Homi Bhaba's work on atomic energy, which lead to present-day successes of nuclear sciences in India.

We shall now discuss the post-independent (1947 onwards) scenario of India. Science was given priority in the economic development five-year plans in India. Within two months of India becoming a republic, the Planning Commission was set up to prepare a blue print for India's future, roughly once in five years. The Tenth Plan (2002–07) targets a GDP growth of 8% a year. In addition to setting up the University Grants Commission, the Government established some outstanding institutions, which have promoted science and technology; for example, the Council of Scientific and Industrial Research (CSIR) and the Atomic Energy Commission. The seven Indian Institutes of Technology (IITs), the first set up in 1951 in Kharagpur (West Bengal) and others later on in Chennai (Madras) (Tamil Nadu), Mumbai (Bombay) (Maharashtra), Delhi, Kanpur (Uttar Pradesh), Guwahati (Assam), and Roorkee (Uttaranchal), produce some 2000 graduates each year and are one of the main sources of technical manpower. Among the IITs internationally known alumni are Victor Menzes, Managing Director, Citibank; N A Rajat-Gupta, Managing Director, McKinsey & Co; Vinod Khosla, a partner in Kleiner Perkins and the co-founder of the Sun Microsystems; Arun N Neteravali, President – Research, AT&T Bell Lab; N R Narayana Murthy, Chairman, Infosys Technology Ltd. The list goes on.

Information technology

Exports from the Information Technology (IT) industry in India are worth US$ 10 billion, which is about 20% of India's exports. During the last 20–25 years, this industry has changed the world's perception of India that it is not a country of only snake charmers. The company Moser-Baer, located near New Delhi is the world's third largest optical media manufacturer and the lowest-cost producer of CDs. This company has acquired Capco Luxembourg, a firm that owns 49% of a Netherlands-based CD distributor. It has set up Glyphic Media Inc. in the United States for markets in North and South America. Similar advances in technology have been made in various sectors, especially in the automobile industry and pharmaceuticals. India is among the three countries in the world that have built supercomputers on their own. Trained manpower in the fields of science and technology in India is being looked upon as a research hub by many multinational companies (MNCs). Over 70 MNCs including Delphi, Eli Lilly, General Electric (GE), Hewlett Packard, Heinz and Daimler Chrysler have set up R&D facilities in India. The GE's John F Welch Technology Centre in Bangalore is the largest outside the United States, with an investment of US$ 60 million and employs 1,600 researchers. The Indian center devotes 20% of its resources to fundamental research having a 5- to 10-year horizon in the areas of nanotechnology, hydrogen energy, photonics, and advanced propulsion. All this has caused "OUT SOURCING" as a major issue of contention in the United States.

Space research

In the three decades of its existence, the Indian Space Research Organization (ISRO) has thrust India into an exclusive space club of a handful of nations by building over a dozen sophisticated satellites, beginning with pioneering Aryabhatta, named after the ancient Indian astronomer, in 1975 for communications, weather prediction and mapping natural resources, telecommunication, and television broadcasting, and boosted India's missile program. With a budget of only US$ 450 million a year – one-thirtieth of NASA's (The National Aeronautics and Space Administration) US$ 15.5 billion budget – India has 13 satellites in the orbit, produces some of the world's best remote imaging satellites, and is planning to send a satellite to the moon by 2007 (Abdul Kalam and Pillai, 2004).

The space program is entirely oriented toward applications for the national development. Example is found in the Majhawan Karan village in Uttar Pradesh, where using satellite imagery, technicians have helped 175 villagers reclaim 40 acres (16.2 ha) of barren land in an area long haunted by hunger. This has changed the lives of subsistence farmers. Another example of space program is seen in Lucknow, capital of Uttar Pradesh, where doctors in the basement of the main public hospital chatted over live satellite link with doctors in rural hospitals hundreds of miles away.

Agriculture

Following independence in 1947, India received considerable technical assistance through the United States Agency for International Development (USAID). Rockefeller Foundation, Ford Foundation, Fulbright, and others trained a large number of Indian agricultural scientists in USA. Through joint technical programs with land grant universities in the US, agricultural universities were set up in India. This resulted in the "Green Revolution" in the 1970s. Early in the 20th century, India had faced many famines and deaths due to starvation. Even in early 1960s, famine was looming over India and millions of tons of wheat had to be imported. The then Prime Minister of India, Mr Lal Bahudur Shastri, appealed to the nation to skip a meal every week. In 1966–67 India imported 20 million tons of food grains because it could not feed its 480 million people. After introducing new seeds of wheat from Mexico and rice seeds from the International Rice Research Institute (IRRI) in the Philippines, India produced 17 million tons of wheat in 1967–68 and 71 million tons in 2003. India is now self-sufficient in food grains production and is facing postharvest storage problems. The use of better seed, double cropping, and easy availability of loans saw the food grain production growing by 70% in a decade.

About 40% of our people live below the poverty line today. They face problems of day-to-day existence, with not enough money to buy simple food items. Still, the situation is much better than what it was during many periods before independence and even later till the 1960s. Today's teenagers would not know about the near-famine conditions that prevailed in certain regions of the country before independence and even later, and particularly about our dependence on American wheat in the 1960s.

The food crisis and Indian society

Prof S K Sinha, an eminent Indian agricultural scientist who led the Food and Agriculture Panel of the Technology Vision was often fond of quoting the following:

"It is also important to recall the experience of C. Subramaniam, the then Union Minister of Agriculture during the critical years of 1965-66 and 1966-67. He stated that we had to import 10 million tons and 11 million tons during these two years—that was a danger signal; you can't depend upon imported food-grain at that level, particularly when it came from 12000 miles away. During the second year of that critical period of drought, the US President Johnson, because of certain international policies he had adopted, was releasing food grain in driblets. At one point, we reached a stage when the stocks existed for only two weeks and there was nothing in the pipeline." (Swaminathan, 1993)

This crisis gave the country's leadership an opportunity to resolve to become self-sufficient in food grains. This period also coincided with a breakthrough in technology at international centers for improvement of rice and wheat varieties. India took advantage of these technologies, experimented with them, and launched large-scale agricultural extension services, instead of viewing these technologies merely as research curiosities. Within three years the production of wheat doubled. This led to food grain self-sufficiency in the 1970s when we developed rice and wheat varieties that were acceptable to our people. Later when two of the worst droughts of the century occurred in India in 1979 and 1987, the world did not take note of them because no food aid was asked for. The country now has a buffer stock of about 35 million tons of food grains. The 1990s have seen a certain degree of diversification of agriculture and exports of various agricultural products including wheat and rice. There is also a growth in the agriculture-based processing industry.

Future needs and capabilities

So can we rest our oars, comforting with the belief that there are no more problems on the food front? Will there be no possibility of a repetition of the humiliation and stress the country and our people had to go through from 1965 to 1967? From Table 2, it seems India may have to import about 14 million tons of food grains by 2010 and then imports will grow at the rate of 2% every year. Along with many others who have studied these issues in depth and thought about possible solutions, we believe that we need not accept these projections at all since India has enormous potential for increasing food grain production. India either already has the necessary technologies or can develop them easily. Our people and our farmers are exceptionally entrepreneurial, and have proved it repeatedly. But we can belie the gloomy predictions only if we resolve to work hard with a long-term vision.

Challenges to Indian agriculture

Thus the growing demand for food grains, vegetables, fruits, milk, poultry, and meat as well as cash crops will present newer challenges to agriculture (Table 3). Let us not forget that our existing food security has been mainly brought about by the increase in irrigated agriculture and the introduction of high-yielding varieties of crops. Current stability in production is through wheat, largely a winter crop. However, the rainfed areas, which account for 70% of the cultivated area of the country, have not benefited from the modern developments in agriculture. Of this 70%, about 30% area is under dryland agriculture where annual rainfall is only up to 400 mm.

Table 2. Projected grain imports (million tons) in 2000 and 2010.

Country/Region	2000	2010
South Asia	9.2	12.8
East Asia	31.4	39.0
India	6.9	14.1
Pakistan	2.1	4.5
Indonesia	5.7	7.6
China	11.3	21.6

Source: TIFAC, Food and Agriculture: Technology Vision 2020.

The problems in areas with rainfed agriculture need to be understood. Lesser the rain in an area, greater is the trouble for the farmers and villagers. During many seasons, it was rare to find even blades of grass. Now in some areas in arid Rajasthan, one is struck by the change brought about by irrigation waters of the Indira Gandhi Canal. The change in the quality of the people's lives is something that gives immense satisfaction and one visualizes India with many such canals – big and small – connecting different river systems and water bodies, and well-managed water harvest and watersheds, thus benefiting the poor.

What is to be done with the rainfed regions till then? Leave them to the centuries-old toil of their farmers? Or neglect them with the hope that we may be able to make a breakthrough in newer technologies so that India can achieve whatever we want from the current 30% irrigated, relatively affluent agricultural zones? There have been several successful small experiments in different parts of both the rainfed and dryland areas of the country. For example, there has been considerable success in some pockets of Maharastra in conserving water, planting of trees, developing village-level grazing lands and regulating water use by the community. This has helped in raising suitable crops and livestock and in creating a viable market system. We should recall how the Green Revolution took place. Several farmers from the irrigated regions of India were given opportunity to visit other parts of the world. Should we not as a country extend similar opportunities to the farmers in the rainfed and dryland regions of our country, at least to visit other places within the country (and if possible to go abroad too) to observe for themselves the successes of farmers there who have overcome similar adversities to increase productivity?

Table 3. Projected household demand for food in India at 7% income growth.

	Annual household demand (million tons)				
Commodity	1991	1995	2000	2010	2020
Food grains	168.3	185.1	208.6	266.4	343.0
Milk	48.8	62.0	83.8	153.1	271.0
Edible oil	4.3	5.1	6.3	9.4	13.0
Vegetables	56.0	65.7	80.0	117.2	168.0
Fruits	12.5	16.1	22.2	42.9	81.0
Meat, fish, and eggs	3.4	4.4	6.2	12.7	27.0
Sugar	9.6	10.9	12.8	17.3	22.0

Source: TIFAC, Food and Agriculture: Technology Vision 2020.

Our people and farmers are all integrated into one huge market. All concerned need to be educated about another important scientific fact through observations, discussions, and mass contacts; i.e., the agro-ecological considerations. The drylands of Central India cannot have high productivity rates of rice and wheat, which are the major food grains relished by Indians. Therefore, agricultural activities in the Central Indian drylands can be focused on pulses, oilseeds, vegetables, fruits, and livestock. Wheat and rice can be concentrated in more suitable regions. Each state should concentrate on agricultural products most suited to its agroclimatic conditions, as it cannot hope to be self-sufficient in all the essential commodities. Suitable marketing and transportation systems can be evolved to facilitate the exchange of commodities. In addition, special attention should be given to agriculture in the eastern region of India through increased productivity. Large parts of eastern India, though blessed by excellent agroclimatic and water resources, have a very low productivity. This situation has to change if India aims at food security and economic prosperity.

There is a need for multi-pronged action. Merely having better seeds or better irrigation will not suffice. The tasks involved today are much more complex than they were during the Green Revolution.

Environmental problems and international pressures

In the coming years we cannot address our agricultural problems in isolation. The General Agreement on Trade and Tariffs (GATT) and the obligations to the World Trade Organization (WTO) have implications for the future course of agricultural research and development and other initiatives we may take. These relate to giving market access to other countries in selling their products in India. This will place a demand on quality and efficiency in our own agricultural operations. Limits will be also placed on how much domestic support we can give to our agriculture.

Restrictions in terms of sanitary and phytosanitary measures, both for import and export of agricultural commodities, will be imposed. This means there will be demands that residues of pesticides and chemicals be reduced to the internationally acceptable standards. If we say that we would adopt these standards only for exports and not for our own domestic markets, then our own people, starting with environmental activists, will insist that we should also adopt international standards as otherwise the health of our people will be in danger. Thanks to the present-day information technology, the demand for stiffer environmental standards in any one part of the world soon becomes a global issue. Thus the use of agrochemicals and fertilizers has to often conform to international specifications. There are also other considerations of "equal national treatment" under the WTO. In other words, we cannot have one standard for Indian business and another for a foreign entity.

Serious implications arise from various international obligations for the protection of Intellectual Property Rights (IPR). This means far greater commercial restrictions in the use of technologies developed elsewhere in the world. Even our own research cannot be based on mere imitation of foreign technologies. For example, we cannot assume easy availability of better seeds as we had obtained through the Mexican high-yielding varieties at the beginning of the Green Revolution. The well-known Basmati rice controversy between the United States and India is witness to the current trend of foreign scientists and technologists attempting to patent an agriculture-related invention. Let us go back to Table 2 which projects possible food grain imports by a number of countries with huge populations. If a number of them do import, many companies in developed countries will resort to selling food grains as a business. (Even now they do through ways that are not too obvious.) Once we depend on imports to provide food for our people, foreign companies and government can use this issue politically to derive many trade and political advantages. It is also likely that they will resort to conditions, which will perpetuate the dependence.

An environmental concern that is likely to have implications for Indian agriculture is the emission of gases like methane and carbon dioxide. These are calculated as based on various models. India will be told that we contribute so much and there may be some penalties on those who emit more than an internationally established limit. Some of the concerns could be real but some could be an outcome of complex geopolitical motivations. The latter can assume various forms to mask pressures. In any case we have to learn to make our own models and counter geopolitical motivated pressures. Further, since climatic changes will affect agriculture, we should also be able to filter out facts of scientific relevance and take advance action to protect our agriculture.

Emerging technologies

In addition to representing the national will and organizing a large-scale national effort, technologies play a crucial role in achieving food security for the country. We would naturally start with biotechnology as it deals with many aspects of basic inputs to agriculture: seeds, plants, soil treatment, etc. It is crucial to food security, if we take the right steps. An important technology is the production of transgenic plants, i.e., plants that are "human-made" and are tailored to meet the desired objectives by transfer and expression of the desired type of gene to a target plant. Transgenic varieties of crops are being produced around the world. Satellite imagery and remote sensing are making rapid progress. Some developed countries monitor crop yields of other countries to help their own exports. India is strong in the area of remote sensing technologies. We have our own high-resolution remote sensing satellites whose pictures are used all over the world commercially. We also have excellent capabilities in utilizing remotely sensed data for various applications: groundwater targeting, soil salinity assessment, crop yield estimates, and so on. In addition, space technology can be used very effectively to assist extension work: disseminate success stories to farmers, educate them with do's and don'ts, and help them ask questions through talk-back facilities that can be made available through satellite. A number of experiments conducted by ISRO in this regard in Maharashtra and Madhya Pradesh have to be extended to other states in a major way. Our farmers should and can be given facilities to keep pace with advances in agricultural technology. Yes, it is a lot of effort. But we have plenty of talent and also the resources.

Vision

It is difficult to express this vision and action in few words. However, to focus on crucial issues, we have attempted to list a few important items below:

- India to aim to be a major player in the world in the agricultural sector and a leading exporter of grains and other agri-products.
- Eastern India to become a major producer of wheat.
- Rice-producing areas to use hybrid seeds on a large scale.
- Central India to be made a center of vegetables, fruits, pulses, and coarse grains.
- More emphasis on tuberous crops.
- Water as a national resource and water management as the key to agricultural prosperity.
- Core postharvest technologies to be mastered and disseminated.
- Steps to educate farmers about what is happening elsewhere, if needed by providing them the opportunity to travel, and use of space technologies to facilitate interaction and encourage farmers to ask questions and share experiences.

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