Oryza sativa L.

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Contents

1.0 Introduction

Rice, or *O. sativa*, is the world's staple food. It is present in almost every region, every climate zone, it feeds millions a day and it is the most economically traded and taxed crop or livestock product in the world. It is a crop that has accompanied humanity through our evolution since its domestication around 12,000 years ago. Rice is a crop many take for granted, and still consume it not only any day, but with every meal. It is one of the only foods that has become a staple in many countries around the world regardless of their culture.

This monograph will attempt to illustrate rice's history, distribution, how it grows, what it needs, and its economic power over the world. In the second chapter, you will find the ecological requirements for rice, its origin and family. In the third chapter, its biology, life cycle, and phenology. Chapter four describes the growth and maintenance of a rice field, while chapter five touches on rice's economic standings and its products.

2.0 Ecology

2.1 Affinities

What we know as rice is actually the seed of the species *Oryza sativa* which is a domesticated branch of the *Oryza* genus. *O. sativa* is more commonly known as “Asian rice” while the less common *O. glaberrima* is distributed as “African rice.” What we know as “Wild rice” are the seeds of primitive and uncultivated *Oryza* species. Rice is currently the most widely consumed staple food for over half of the world's human population and as an agricultural product ranks third for highest production after sugarcane and maize (Kelman, 1995). Since sugarcane and maize are produced for uses outside of human consumption, rice is the most important food crop with regard to human nutrition and caloric intake, providing more than one-fifth of the calories consumed worldwide by humans. (Smith, 1995).

The massive worldwide production of rice makes its industry a dangerous contaminant and a prominent source of carbon emissions. The *Oryza* genus arose millions of years ago, giving it time to branch out among various regions, climates, and conditions. This has resulted in the presence of this crop almost everywhere in the world and a myriad of subspecies under the *Oryza* genus. It has become an extremely versatile crop, being able to exist in many regions of the world and still be a productive and domesticated agricultural product. (Xie et al., 2010).

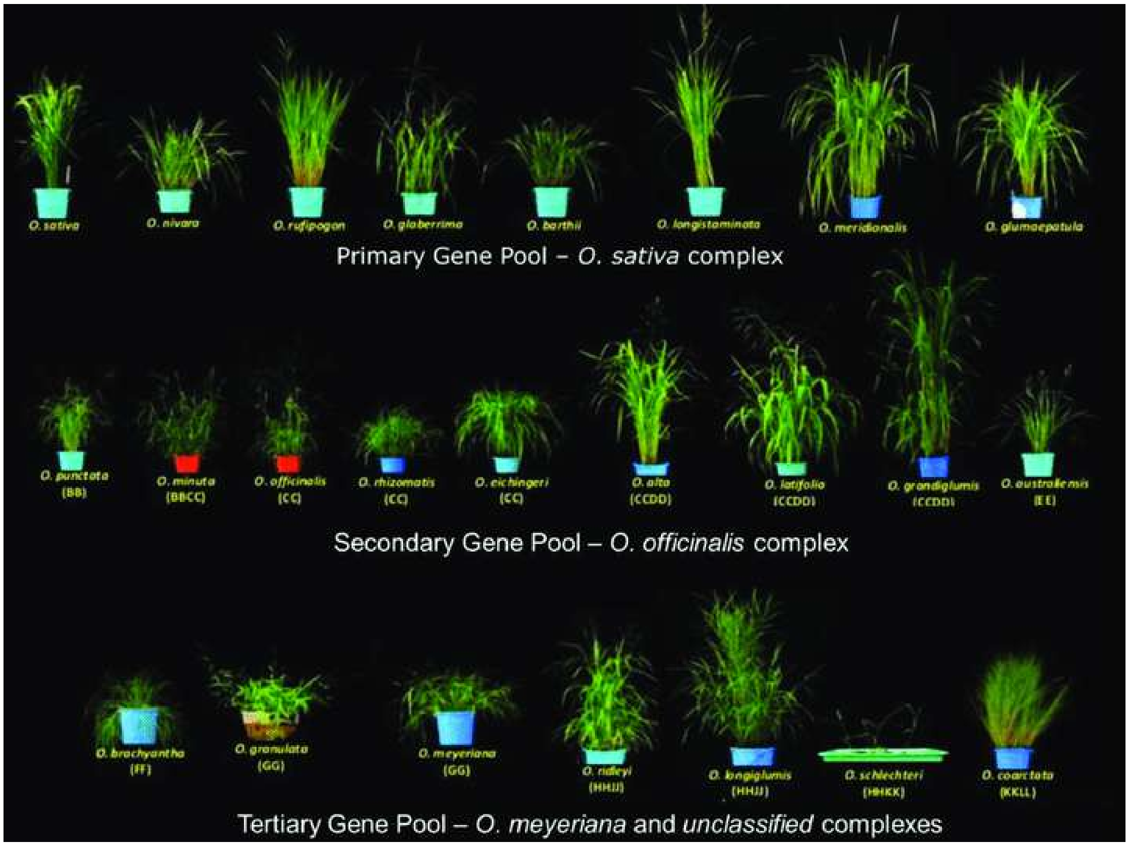

Figure 1, Gene pools of the genus *Oryza* and its different species variations. (Zhong-Hua, 2020).

2.2 Ecological Requirements

2.2.1 Climate

Rice is a very demanding crop, it requires a lot of water and humidity in order to thrive. At the same time, it is one of the most widespread crops and as a global food staple, it has been thoroughly studied and adapted to different climates and regions. (McDonald, 1977). In India, one of the world's largest rice producers, rice is grown in regions with high humidity, prolonged sunshine, and an assured supply of water. (Yadav & Agropedia, 2009).

2.2.2 Temperature

The optimum temperature required to grow rice varies from 21 to 37º C but anything above 42 or below 15º C will kill the plant or prevent germination. (Chand, 2014). The suitable temperature range for rice varies depending on its stage of development. The temperature required for blooming is in the range of 26.5 to 29.5º C. At the time of ripening the temperature should be between 20-25º C. (Yadav & Agropedia, 2009).

2.2.3 Soil

Due to rice's high water needs, the soil onto which it is planted must fulfill a certain set of characteristics. First and foremost, the soil needs to have a very high water retention capacity to minimize the need for watering and the possibility of excessive watering. The soil must also count with high amounts of clay, a pH between 5.5 and 6.5, and a high presence of organic material for optimum growth. Although rice can grow in almost every soil, failure to meet the criteria above will cause the production rate and productivity of the rice to decline. (Tamil Nadu Agricultural University, 2021).

Rice is commonly grown in a submerged state even though it is not an aquatic plant. This is a practice that started recently due to the high water demands of *O. sativa* and an increase in weeds and other pests. The water that covers the stem of the plant provides it with a cover to weeds and insects while also supplying the plant with water. Rice is not aquatic, but its tolerance and needs for water are so high, it is able to just barely survive and be productive while submerged. (Goud, 2005). While this was an innovation not long ago, submersion seems like a prerequisite for everyone looking to grow rice today. Due to this practice, the environmental impact of rice cultivation has become more harmful. The Guardian, citing the Institute of Mechanical Engineers measured around 2,500 and 5,000 liters of water are needed to produce just one kilogram of rice grains. (The Guardian, 2013).

Figure 2, A farmer inspecting a crop of deepwater rice. (International Rice Research Institute, 2008).

2.2.4 Rainfall

Rice needs a lot of water to grow. About 150 cm or more of annual rain is the bare minimum needed for the plant to thrive. (Aryal, 2013). Due to this, the main areas of rice cultivation average anything between 175-300 cm of annual rainfall. In India, one of the world's largest rice producers, and other parts of southeast Asia, rice is considered a "Kharif" crop. This means it is one of the 5 main crops (Rice, maize, bajra, ragi, soybean) that is sown right before the monsoon and rainy season. (Chand, 2014)

2.3 Fossil Records

Rice has existed since the cretaceous periods. Evidence in paleobiogeography has shown *O. sativa* to have been present in late cretaceous India about 65-67 million years ago. (Prasad et al., 2011). However, very similar fossils of *O. sativa* have been found in Australia and its neighboring islands, dating to very similar periods. This, of course, is suggesting that a very early species of wild rice must have been present in *Gwondana,* the southern hemisphere of Pangea, where India and Australia were connected. This would explain the presence of *O. sativa* in both regions. (Vaughan et al., 2005).

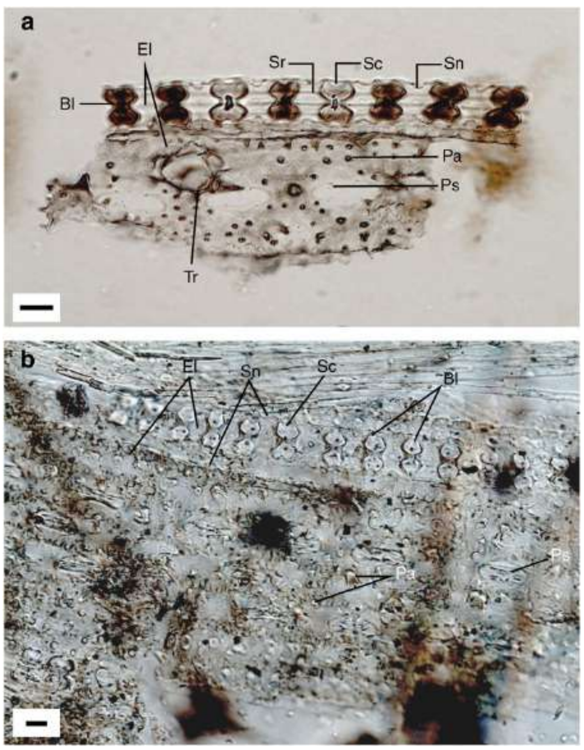

Figure 3, Fossil cuticle with phytoliths (silica and tissue that persists after a plant's decay and decomposition) found in India. (Prasad et al., 2011).

2.4 Historical Distribution

There is a consensus around the world regarding the origins and domestication of rice (*O. sativa*). Archeological evidence has proved that rice was first domesticated in the Yangtze River basin in China 13,500 to 8,200 years ago. Not long after, *O. sativa* spread to other parts of eastern Asia and eventually reached western Asia and Europe. (Vaughan et al., 2008).

There is a controversy regarding the origins of rice. Being one of the first crop species, there is little evidence dating all the way back to its origin. This has resulted in a group of historians who, ignoring the scientific evidence of its presence in the Yangtze river basin, believed rice originated in India. (UCL, 2018). There is an older study, from 2006 based on analyzing the nuclear gene regions, that suggests *Oryza sativa* was domesticated twice, Indica in India, and Japonica in China. The study also recognizes that archaeological and genetic evidence exists for a single domestication of rice in the Yangtze river basin. (Londo et al., 2006).

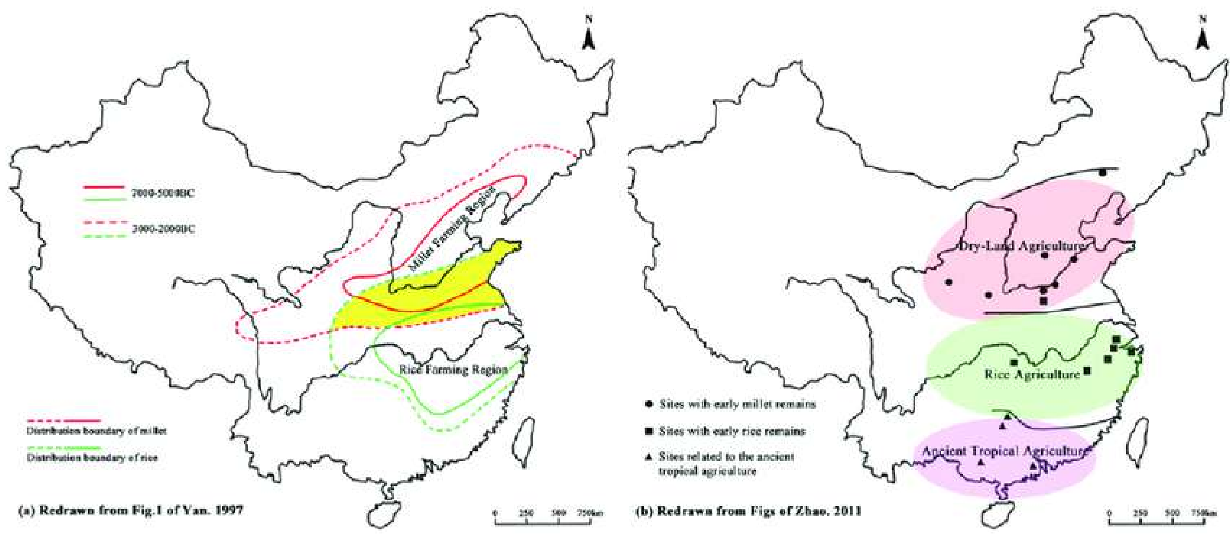

Figure 4, Division and evolution of agriculture in Neolithic China according to the scheme proposed by (a) Yan (1997) and (b) Zhao (2011b). (He et al., 2017).

2.5 Current Distribution

Rice is the world's largest food crop. Grown over an area of over 1.5 million square kilometers, it is second in terms of area and production only to wheat. (Tamil Nadu Agricultural University, n.d.). It is a global food staple, currently found growing in Africa, the Americas, Europe, and more. Rice is currently one of the most affordable and cost-efficient crops in the world, it is used in various global food programs to end hunger and malnutrition. Its extensive presence around the world and its convenience results in rice providing 27 percent of dietary energy supply and 20 percent of dietary protein intake in the developing world. (FAO, 2004).

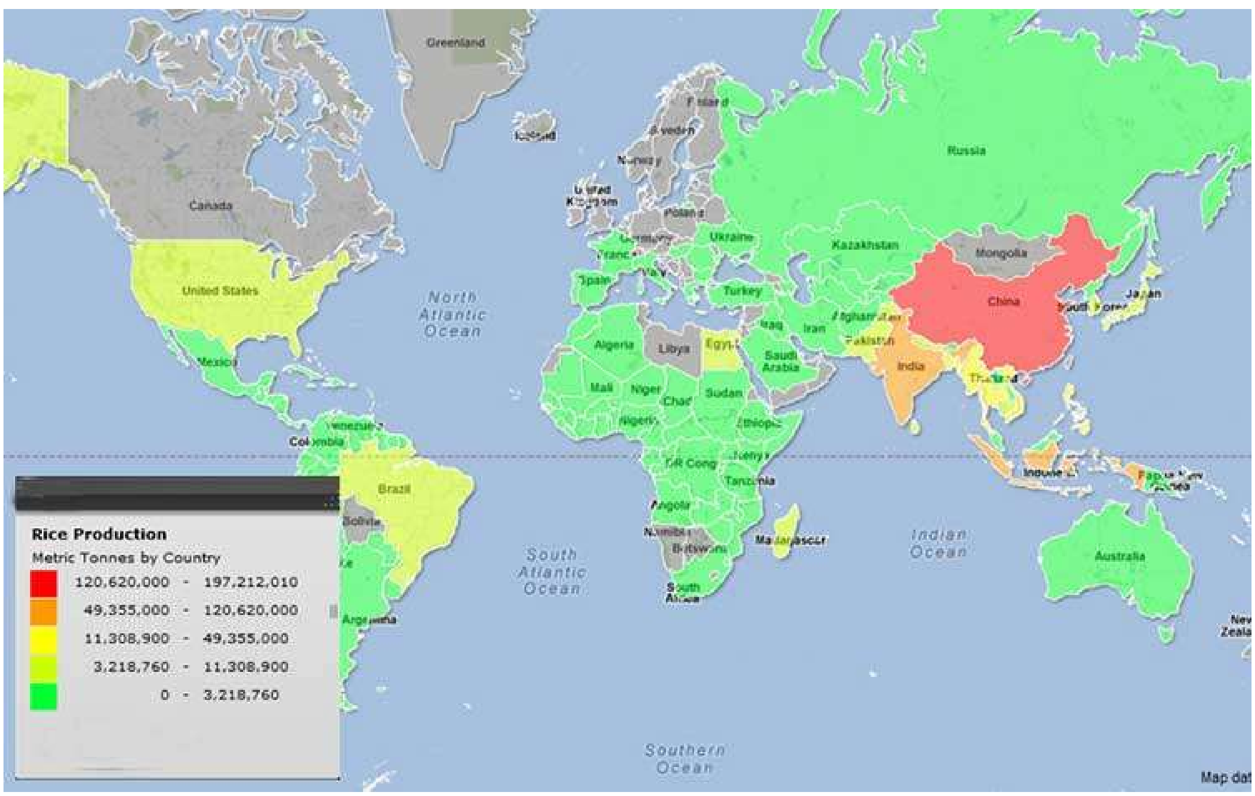

Figure 5, Rice production in 2018. (GEMCO Rice Husk Pellet Mill, 2018)

3.0 Biology

3.1 Life Cycle and Phenology

Rice undergoes three main developmental phases after germination: vegetative, reproductive, and ripening. *O. sativa* takes around 3-6 months to fully mature from germination, this all depends on the varying environmental conditions and the subspecies. More specifically, rice can be categorized into two main variations; the short-duration varieties which mature in 105–120 days, and the long-duration varieties which mature in 150 days. The average 120-day maturation rice plant will spend 60 days in the vegetative phase, 30 days in the reproductive phase, and 30 days in the ripening phase in tropical conditions. (Ricepedia & International Rice Research Institute, 2021).

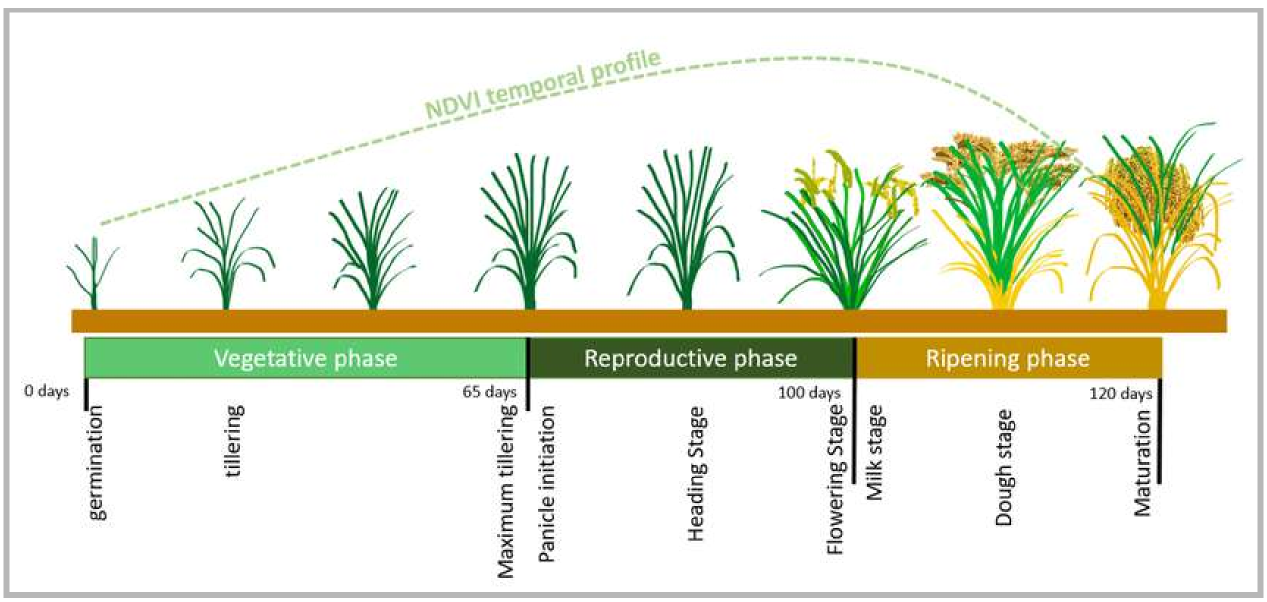

Figure 6, Rice plant cycle with phase and froth stages. (Aguilar, 2015).

3.1.1 Vegetative Phase

The vegetative phase in rice typically lasts from 55 to 85 days and it begins as soon as the seedling sprouts from the seed. It is mainly characterized by root growth, leaf sprouting, growth of tillers, and a substantial increase in plant size. (California Rice Production Workshop, 2018).

3.1.2 Reproductive Phase

The reproductive stage of rice begins when the panicles start branching off the stems. After the panicle fully emerges rice is in a stage of “heading” which lasts one day before flowering begins. Flowering lasts approximately 7 days in which the flowers drop pollen onto themselves. (Ricepedia & International Rice Research Institute, 2021).

Figure 7, A rice panicle in Bangladesh. (Gain, 2013).

3.1.3 Ripening Phase

Ripening begins after flowering and ends with the harvest. Rainy seasons and cold fronts can increase ripening times while hot, tropical weather shortens them. Ripening times vary with subspecies from 15-40 days and with temperatures ranging from as low as 30 days in the tropics and as long as 65 days in cold weather. (Ricepedia & International Rice Research Institute, 2021).

3.2 Genetics

3.2.1 Genome Sequencing

The International Rice Genome Sequencing Project (IRGSP) began in September 1997, with the gathering of scientists from all over the world and their shared goal of sequencing the rice genome. (Eckardt, 2000). The project was an ambitious one being the third-largest public genome project undertaken to date, behind the human and mouse genomes. It was also the second plant to have its genome sequenced. The first was *arabidopsis*, a weed that was used as the guinea pig for genome sequencing in the plant world. (Patrick-Davis, 2021).

3.2.2 Chromosome Complement

O. sativa has a haploid chromosome number of 12 (2n=24) and has a total length of 430 Mb (megabase, or million base pairs). (Notsu et al., 2002). *O. sativa* has been around for so long and is so spread out around the world, the different subspecies--*indica, aus, temperate japonica, aromatic and tropical japonica*--each have vastly different genetic structures. (Sasaki, 2005). A

Cornell study on the genotype differences of the five main subspecies revealed said differences. *"Unlike maize, tomato and many other crops, Asian rice is highly differentiated into five distinct subpopulations or ecotypes,"* said Susan McCouch, professor of plant breeding and the paper's senior author. *"The genetic differences among these five rice subpopulations are greater than the differences between many cultivated crops and their wild ancestors,"* she added. (Ramanujan & Cornell, 2011).

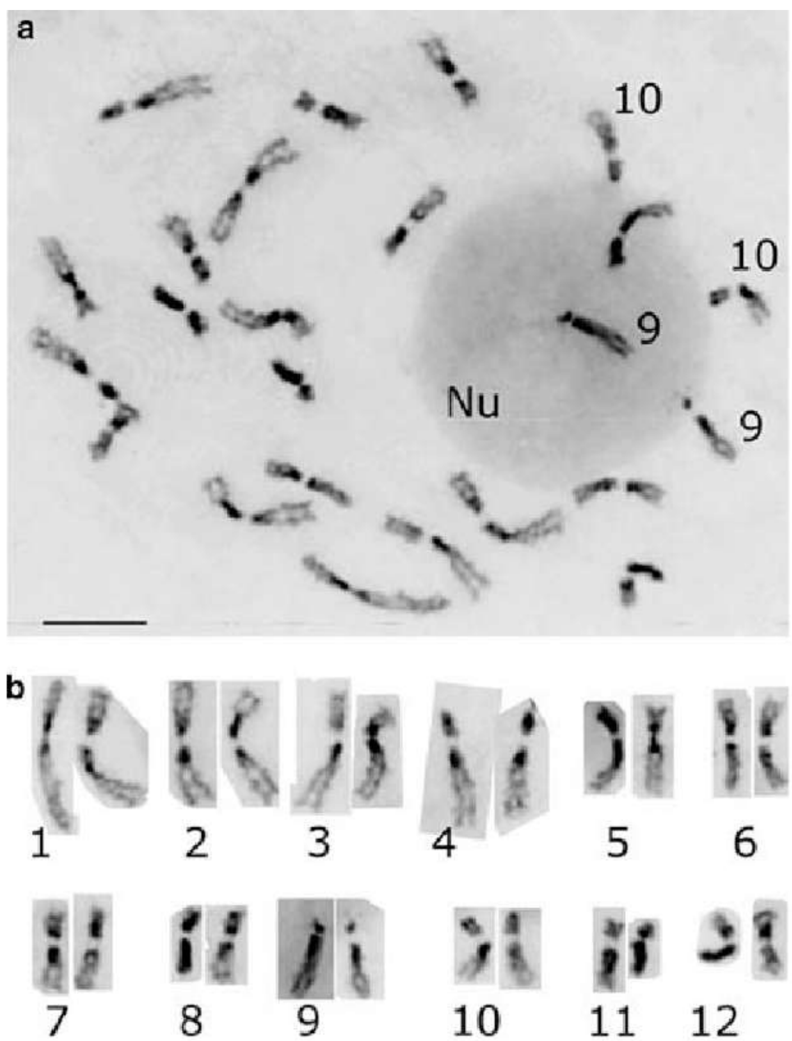

Figure 8, Chromosome complements (a) and karyotype (b) of *O. sativa*. Twelve homologous pairs of chromosomes were arranged according to their morphology and numbered according to their length in descending order. (Lee, 2008). **Nu = nucleolus**

3.3 Reproduction

3.3.1 Pollen

Rice is mostly a self-pollinating crop. One day after the heading stage is completed, meaning the panicles are fully visible, the plant begins flowering and expelling pollen onto nearby flowers in the same plant. (Ricepedia, 2014). A recent study in Chinese wetlands concluded that certain microorganisms like the european honeybee, *apis mellifera,* contribute to the pollination of rice fields. While this contribution is minimal, it is worth noting that these discoveries could have serious implications for the future of mass reproduction of rice. (Chen, 2014). Another innovation that is driving change takes place in Danbury, Texas. In the rice fields that surround the area, the absence of constant wind prevents pollen from traveling far and creating a homogeneous gene pool. To combat this, farmers have begun using Robinson R22 helicopters to fly over the fields and disperse pollen during the reproductive phase. (Head, 2020).

Figure 9, A helicopter flying over rice fields in Texas. (Head, 2020)

3.3.2 Sexuality

To ensure a diverse offspring of the autogamous crop, the sexual reproduction from *Oryza sativa* is wondersome. During meiosis, *O. sativa* begins the process of homologous recombination. During this process, new haplotypes are generated by shuffling alleles. After meiosis takes place, fertilization begins where the fusion of two gametes produces new genotypes of the diploid cell or zygote. (Nonomura & Yamaki, 2008). These two steps ensure genetic diversity but its randomized nature has resulted in the loss of beneficial traits. New technologies are being pushed by the day to allow farmers to clone crops rather than submit to randomness via natural reproduction. (Khanday et al., 2019).

3.3.3 Anthesis

Rice is mainly autogamous or self-pollinating. After pollen has fallen onto anthers the flowerpod closes leaving the anthers outside, this lasts from one to three hours. As soon as this happens the production of a single rice grain commences. After the grain has grown within the flowerpod the process of drying begins where it turns into the dry, solid rice grains we know.

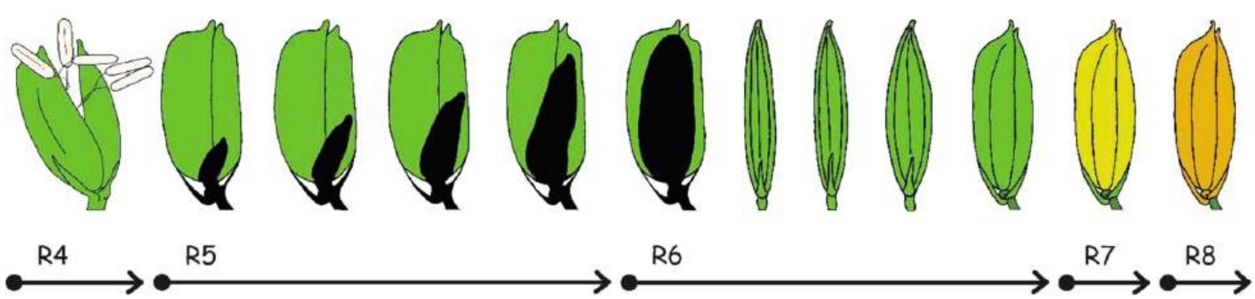

Figure 10, The development of the individual rice grain. (Counce & Moldenhauer, 2019).

4.0 Propagation & Management

4.1 Production

Figure 11, Steps in rice production. (California Rice Commission, 2022).

4.2 Propagation

Being one of the most demanding crops to grow, rice needs very specific characteristics. However, newer technologies and innovations have allowed rice to be cultivated in less conventional areas e.g. drought resistant varieties are grown in upland areas. (Chen et al., 2014). Rice crops can be either direct seeded or transplanted. (International Rice Research Institute, 2016). Direct seeding may be appropriate if you have limited resources, want to reduce labor costs or prefer crops to mature faster. On the contrary, transplanting may be appropriate if you have a space for a nursery, have available resources for seedbed preparation, have equipment for transplanting and labor is not a limiting factor. (International Rice Research Institute, 2016).

4.2.1 Direct Seeding

For seeding, seeds can be sown in the seed beds either manually by broadcasting or through more specialized machinery like drilling. Three main methods are used for direct seeding rice in lowland areas: dry seed beds, wet seed beds and "dapog." For dry seeding, the seeds are spread out in a dry field by broadcasting. Then, the seeds are covered with soil and the bed is over-watered until the seeds germinate. (Chen et al., 2014).

Figure 12, Direct "dry seeding" of rice by manual broadcasting, (Rickman et al., 2015).

Contrary to dry seeding, wet seeding occurs when the seeds are sown in a puddled or overwatered patch of land and are left to germinate.

Last, “dapog” is a more traditional method of seeding rice in the Philippines where the ground is covered with banana leaves and layered with seeds and then flooded. The main merit of this method is that less area is needed to create seedlings and the seeds sprout quicker. (International Institute of Rural Reconstruction (Silang), 1990).

Figure 13, Nursery preparation for “dapog” seeding of Rice, (Agriquest Baba, 2017)

4.2.2 Transplanting

Transplanting is another alternative to direct seeding. In this case, rice seeds are sown using one of the methods described above in nurseries and then transplanted to the actual field. For dry seed beds, these have to be arranged in close proximity to a constant water source. Each bed is around 1.5m wide and is seeded at a rate of 10kg of seeds every 10 square meters. (Chen et al., 2014). Wet seed beds are raised beds in which seeds are sown. The bed is puddled or overflowing with water and the seeds are spread out and partially submerged. (Rickman et al., 2015). Dapog seed beds are basically what was described above but on a smaller scale. In this method around 25 to 30 square meters of area is enough to sprout seedlings that can cover one hectare once transplanted. The seedlings raised by this method are, however, very delicate and survive only for about two weeks in the seed beds. (International Institute of Rural Reconstruction (Silang), 1990).

Figure 14, Farmers carry rice seedlings for transplanting at a paddy field in Mehtarlam, capital of Laghman province, eastern Afghanistan. (Saifurahman, 2021).

4.3 Management

Oryza Sativa is a tricky crop to grow and sustain. Not only does it require an absurd amount of water and constant climate, but the rice industry has perfected their methods for optimum harvest of rice. The rice industry today is technology-driven; with groundbreaking innovations surfacing everyday and helping farmers grow their rice. (USA Rice, 2020). Today, satellites are being used to monitor and predict weather conditions over rice fields, laser landforming creates the most efficient irrigation systems, and spectral imaging allows farmers to calculate the exact capabilities of their farm by identifying enterprises to suit each area. (RGA, 2019). Every day, new varieties of rice are designed in laboratories to withstand different conditions. “Sherpa” rice was released in 2011 with a much higher cold tolerance than conventional rice, while “Topaz” was released in 2014 to withstand Australia’s dry environment. (RGA, 2019)

Figure 15, Traditional rice and “golden rice,” a genetically modified rice strain with a much higher content of Vitamin A. (McKie, 2019).

4.3.1 Irrigation

The first ever irrigation of sown rice seeds is of utmost importance as it affects germination. In this first irrigation, it is recommended to use the “seeping irrigation” method where a large amount of water is retained on a portion of the field where it can seep into the soil and wet the seeds. For the second irrigation and onwards, farmers can use the “flood irrigation” method which is the most common method for growing rice around the world. This method consists of basically flooding the fields to meet with the crop’s high water demand. (Water Science School, 2018).

Figure 16, Flood irrigation in a field. (McMahon, 2022).

4.3.2 Pesticide and Herb Control

Farmers lose an estimated average of 37% of their rice crop to pests and diseases every year. In addition to good crop management, timely and accurate diagnosis can significantly reduce losses. Rice suffers from a grave variety of pests, including but not limited to birds, insects, snails (in southeast asia), diseases, funghi and rats. The larger animals are controlled with different pesticides, however diseases like blast, bacterial blight, sheath blight, and tungro virus require a different approach. (International Rice Research Institute, 2018). Due to the advancement of technology that allows the creation of rice hybrids, there are now many strains of resistant or even immune rice. Oftentimes, the simpler and most effective solution to manage these pests is planting a resistant variety. (International Rice Research Institute, 2017).

Figure 17, Rice infected by the “Sheath blight” fungus which causes the premature decay of leaves. (Uppala & Zhou, 2018).

4.3.3 Fertilizer Application

For Oryza sativa, the optimum fertilizer dose is two to three bags of urea (100 to 150kg) per hectare of field. The urea must be applied in certain stages to maximize the yield of the crop. The first application must be around 20-25 days after sowing when the plant has 4-5 fully grown leaves. The second application is about 15 days after the first application. (Gaihre, 2020).

4.3.4 Harvesting

It is internationally recognized that optimum harvesting stage is when grain panicles are 80% fully mature as shown below. When harvest occurs at this stage, high quality rice is produced with minimum harvesting loss. Due to its high water demands, rice grows in a very humid environment. After harvesting, rice needs drying in the sun to reduce the moisture levels inside the grain and prevent yellowing and mold outbreaks. (USA Rice, 2020).

Figure 18, Mature rice panicles in Korea. (IRRI, 2004).

5.0 Marketing and Economy

5.1 Global Trade

According to the Observatory of Economic Complexity, rice is the world's 134th most traded product, and the 1st most traded livestock or crop product, with a total trade of $26.8B. Between 2019 and 2020 the exports of Rice grew by 5.97%, from $25.3B to $26.8B. Trade in Rice represents 0.16% of total world trade. (OEC, 2020).

5.1.1 Imports

Being grown almost everywhere, *O. sativa* itself is rarely traded. In reality, aromatic, endemic strains of *O. sativa* make up the rice trade of the most developed nations.

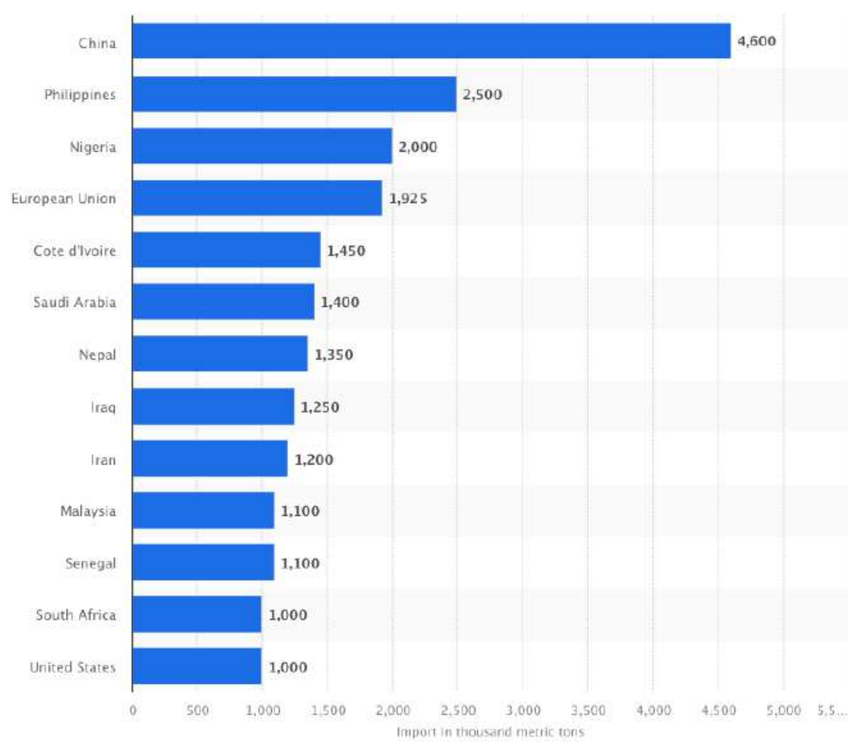

Figure 19, Largest imports of rice in the world (2021/2022). (Shahbandeh, 2022).

5.1.2 Exports

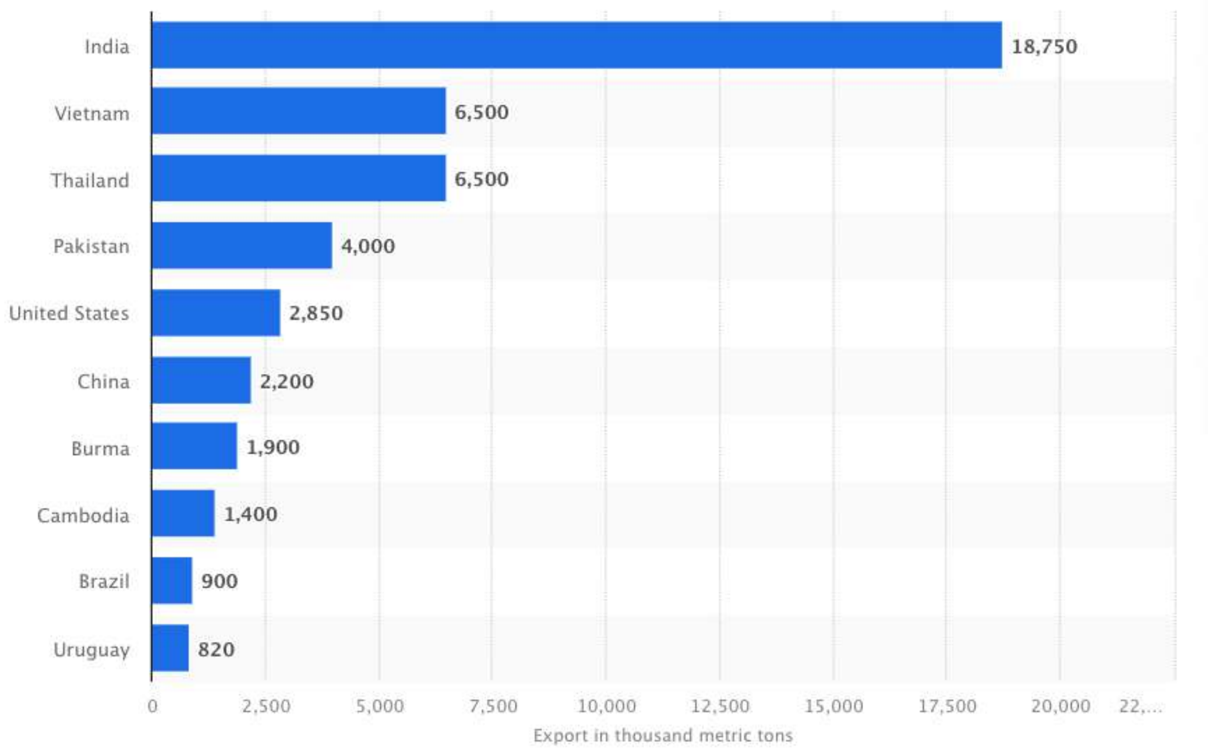

Figure 20, Largest exporting countries of rice (2021/2022). (Shahbandeh, 2022).

5.2 Products

5.2.1 Food Products

5.2.1.1 Rice Flour

Rice flour is obtained after grounding raw rice. It can be made from either white rice or brown rice and it is used for cooking as a substitute for wheat flour or as an ingredient in confections. Due to its glutinous properties it is used to create all types of buns and doughs in asian cuisine. Rice flour is also used in the cosmetic industry. (Alden, 2005).

Figure 21, Mochi ice cream, a traditional Japanese dessert made with rice flour.

(Wikipedia Commons & Bekago, 2020)

5.2.1.2 Jasmine Rice

Jasmine rice is a long-grain variety of *O. sativa* which is characterized by its aromatic properties. Its smell, similar to popcorn, is due to the presence of *2-acetyl-1-pyrroline*, an aromatic compound. (Wongpornchai et al., 2003). Jasmine rice is grown primarily in Thailand, Cambodia, Laos, and southern Vietnam. It is moist and soft in texture when cooked, with a slightly sweet flavor. (Kosov, 2015).

5.2.1.3 Basmati Rice

Similar to Jasmine rice, Basmati is a slender aromatic rice that counts with the presence of *2-acetyl-1-pyrroline.* Basmati rice is traditionally grown in India, Pakistan, and Nepal. However, India alone accounts for more than 70% of the production of Basmati rice. (FAO, 2015). As a matter of fact, the word "Basmati" is derived from the Hindu word for "fragrant." Curiously enough, the Canadian Diabetes Association found that Basmati rice has a much lower glycemic index than other types of rice, making it more suitable for people who suffer from diabetes. (Canadian Diabetes Association, 2018).

5.2.1.4 Other Types of Rice

Rice is one of the most distributed crops in the world. Due to this, there are thousands of variations of *O. sativa* that are commercialized around the world for its different properties. Some examples of other types of rice varieties are:

- Arborio rice
- Black rice
- Wild rice
- Bomba rice
- Calasparra rice
- Brown rice
- Red cargo rice
- Rosematta rice

Figure 22, Different types of rice. (Hae-Jin Li, 2022).

5.2.2 Non-Food Products

5.2.2.1 Rice Straws

Rice straw is the name given to the other part of the plant that is not eaten. This part of the plant (including the leaves) is used traditionally in Japan to avoid burning it and polluting the air. The Japanese use these leaves to create their "Tatami," a woven textile used for roofing and mats. (Japanology, 2018).

Figure 23, a woven Tatami mat. (Teyssier, 2019).

5.2.2.2 Rice Husks

Rice husks are the hard protective covering that grows with rice. It is slightly larger than the rice grain, has a brown color and comes in a convex shape. Rice husks can be put to use as building material, fertilizer, insulation material, or fuel. Rice husks are not edible but there have been reports of them being eaten during times of food scarcity in China. (Fahim & Bhupinder, 2021)

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