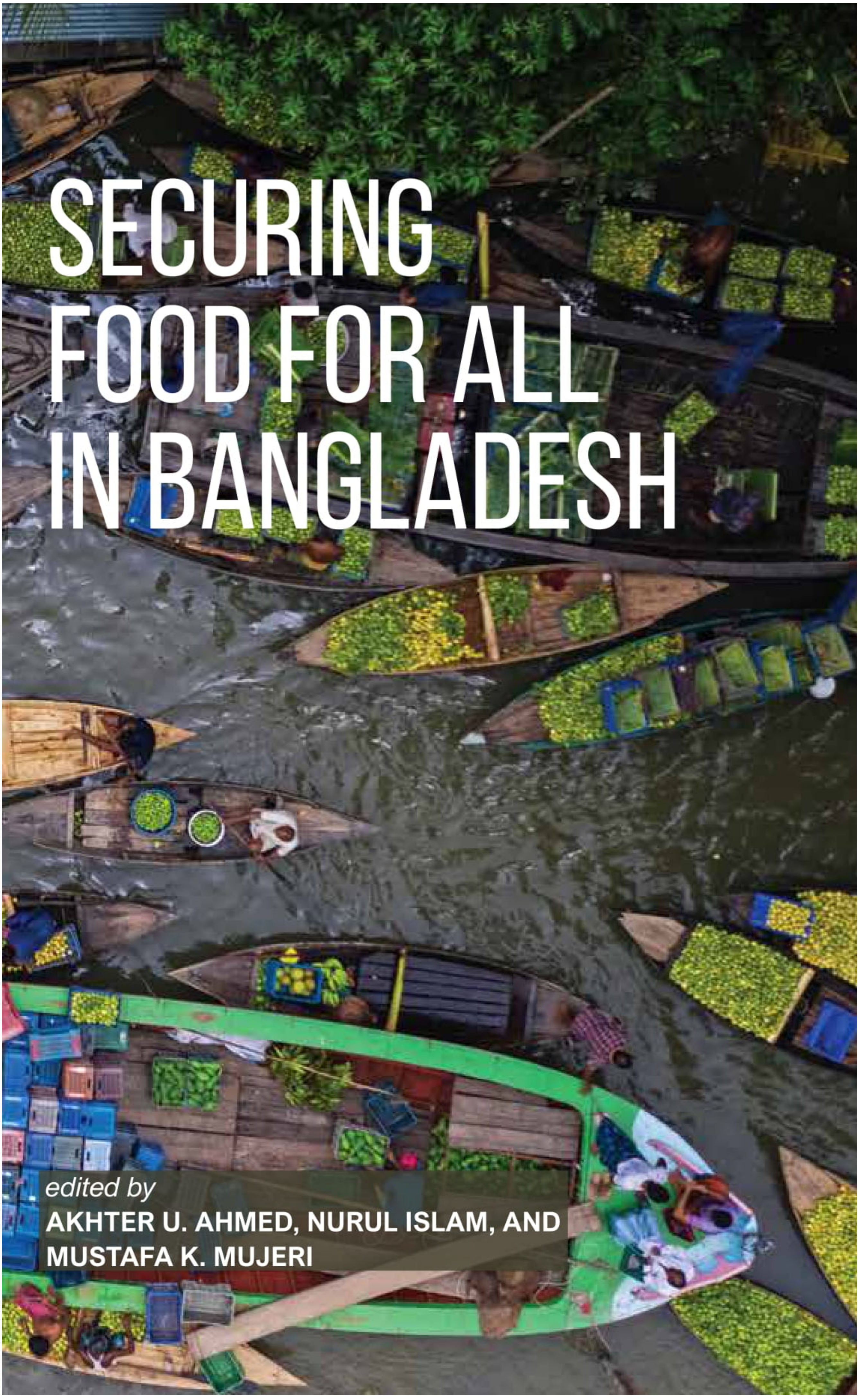

SECURING FOOD FOR ALL IN BANGLADESH

edited by
AKHTER U. AHMED, NURUL ISLAM, AND MUSTAFA K. MUJERI

Chapter 2

Challenges and Opportunities for Hybrid Rice in Bangladesh[1]

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2.1 Introduction

Many studies suggest that hybrid rice can contribute to food security in developing countries, especially in parts of Asia where rice production is so vital to the rural economy and where rice remains a staple of both urban and rural food consumption. The higher yields attributable to hybrid rice have the potential to increase food availability for farm households' own consumption, while also increasing farm incomes through sales of larger marketable surpluses. These larger marketable surpluses can result in increased food supplies that reduce or stabilize prices for both urban and rural food-insecure households (see e.g. Lin and Pingali 1994; Xie and Hardy 2009).

To a large degree, these touted benefits of hybrid rice have been realized in China, where widespread adoption of hybrids is credited with improving food security and feeding an estimated 60 million additional people per year (Li et al. 2010). Despite the apparent success of hybrid rice cultivation in China, however, the proliferation of hybrid rice has been much slower in many other Asian countries. While over half of total area under rice cultivation in China is used to grow hybrids, hybrid rice cultivation in other Asian countries accounts for a relatively small portion of total rice area. In India, Indonesia, and the Philippines, for example, less than five percent of total rice area is used for hybrids, while only about seven percent of total rice area in Bangladesh and ten percent of total rice area in Vietnam are under hybrids. The sluggish adoption of hybrids is particularly troubling in South Asia, where overall growth in rice yields has been slow in recent decades (Janaiah, Hossain, and Husain 2002).

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[1] An earlier version of the chapter was published in *Applied Economic Perspectives and Policy*, 39, no. 1 (2017): 154-176. This is reproduced with the permission of the publisher.

There exist a variety of challenges constraining the widespread adoption of hybrids outside China. These challenges include not only technical challenges associated with the development of suitable hybrid rice technologies, but also institutional challenges, market failures, and policy constraints that have thus far limited the diffusion of hybrids. This study aims to address these challenges using an integrated conceptual framework that opens the "black box" of the research production function and examines the processes behind the product. Specifically, this chapter examines the factors that encourage or inhibit the discovery, development and delivery of hybrid rice in South Asia, with a particular emphasis on the Bangladeshi context. When applied to overall agricultural science, technology, and innovation policy, this integrated framework helps identify (i) key actors, assets and processes engaged in the production, exchange, and use of new technologies; (ii) actions and interactions that enable these actors to invest in process innovations; and (iii) policies and institutions that influence their actions and interactions. An analysis of the complex systems surrounding hybrid rice can provide a clear picture of the precise areas in which policy interventions can result in accelerated development and delivery.

The chapter is organized as follows. In Section 2.2, we introduce the conceptual framework that will be employed to examine the opportunities and challenges for the discovery, development and delivery of hybrid rice technologies, including an introduction of data used in the quantitative and qualitative analysis throughout the study. In Section 2.3, we provide a historical and contextual background of hybrid technologies in general and some of the specific concerns regarding hybrid rice. In Section 2.4, we review the history and patterns of hybrid rice adoption in Bangladesh, identifying several key constraints, challenges, and risks specific to the Bangladeshi experience. In Section 2.5, we discuss the technical, social, economic, and policy dimensions of hybrid rice. Finally, Section 2.6 concludes with a set of actionable policy recommendations for further research, development and delivery of hybrid rice in Bangladesh.

2.2 Conceptual Framework

While many of the benefits of hybrid rice seem obvious, there are also challenges in transforming a technology such as hybrid rice into an economically relevant production factor. Addressing these challenges requires a better understanding of the complex mechanism by which factors of technology production—scientific capital, technical know-how, breeding materials, and seed production systems—are translated into real outputs, such as marketable quantities of hybrid rice seed or hybrid rice as a tradable commodity itself, and how these marketable outputs themselves interact with complex and diverse consumer preferences in downstream output markets.

One strategy to understand the complex issues related to technology production is to examine the processes by which science is translated into viable technologies and, ultimately, into commercial products, as well as the incentives that motivate individuals, firms, and governments to invest in these processes. This type of examination requires shifting our analytical emphasis to the question of how—rather than why—science, technology, and innovation (ST&I) policies and investments should be made, or focusing on systemic complexity and knowledge gaps rather than cost—benefit analysis.

The integrated ST&I framework used in this study addresses the "how" question by emphasizing the roles played by diverse actors in the production, exchange, and use of ST&I products and processes; the institutions and incentives that condition these actors' actions and interactions; and the precise policy interventions that are most likely to result in welfare-improving outcomes. It does so by focusing on the analysis of optimal investment, collaboration, and risk management strategies that define the critical decision-making points for investment in agricultural ST&I.

The framework examines decision points at three stages of analysis—discovery, development, and delivery. During this process, knowledge, scientific, human, and productive capital are all transformed into marketable outputs and measurable inputs through an iterative process of discovery, development, and delivery. *Discovery* describes the investment, collaboration, and risk management strategies related to scientific and technical inquiry at the earliest phase of innovation. *Development* describes the translation of science into technology and the market opportunities, regulatory hurdles, and other constraints associated with this process. *Delivery* refers to the adoption and uptake of a technology through various market and non-market distribution channels that are influenced by the economic behavior of individuals, firms, and governments.

At the nexus of discovery, development, and delivery is a series of institutional and industrial strategies involving investments, collaborations, and risk management. This iterative process of learning results in innovative technologies (e.g. interactions between discovery and delivery facilitates demand-driven innovations), innovative processes (e.g. interactions between discovery and development facilitate new methods and approaches for streamlining the research and development pipeline), and innovative dissemination (e.g. interactions between development and delivery facilitate new methods for transmitting information about the technologies or for transmitting the technologies themselves).

Table 2.1 summarizes these three stages, highlighting the clearly defined investment, collaboration, and risk management strategies that innovators and policymakers must address when making critical decisions and pursuing specific actions. Where information and analysis are limited and where public policies give little guidance in steering decisions and actions to optimal outcomes, innovators face greater levels of uncertainty. This uncertainty necessarily constrains the assessment of whether or to what degree a given technological opportunity will enhance productivity, reduce poverty, or promote equity in developing country agriculture. Efforts to bridge this information gap and design farsighted public policies are an essential contribution of any analytical work on ST&I.

Table 2.1: Key Stages and Strategies in ST&I Framework

Key stages	Product discovery	Product development	Product delivery
Key function	Basic research and upstream science	Applied/adaptive research and product introduction	Product marketing and distribution
Investment strategy	Identify or acquire relevant research assets; Identify research (technical) strategy	Transform research into a commercial product; Develop production systems and business models for commercialization	Develop marketing strategies and distribution systems
Collaboration strategy	Identify and leverage research networks and partnerships; Review intellectual property (IP) rights needs to identify licensing or collaboration priorities	Identify and leverage product development networks and partnerships	Manage in-house versus outsourced production; Identify marketing partners and partnering strategies
Risk management strategy	Identify regulatory issues associated with the research	Identify market risk issues associated with the product; Collect and manage environmental safety, human safety, and other regulatory data	Manage production and product safety; Manage market risk; Identify industry structure and concentration issues; Ensure IP protection and product stewardship

Source: Authors' estimation.

Necessarily, these differentiated stages of discovery, development, and delivery are based on overlaps and interactions, a reality that draws attention to the fact that most innovative opportunities cannot be exploited simply on the basis of a linear process that moves from upstream science into downstream application. Instead, the process begins with a widely defined set of assets: explicit inputs, such as known stocks of scientific capital, other forms of capital, land, and labor, as well as more implicit or tacit inputs, such as scientific experience, indigenous knowledge, and managerial capacity. The application of these assets to a particular problem or production constraint leads to a non-linear progression influenced by (1) the availability of appropriate tools and technologies (the "state of the art"); (2) the capacity of agents to iterate, learn, and innovate through this progression ("innovative capabilities"); and (3) the existence of appropriate policies and investments in support of ST&I (the "enabling environment"). In short, although ST&I can contribute to solving problems in developing country agriculture, the solutions require more than just good science: they also require the right tools and technologies *plus* the right policies and investments.

This study relies on both quantitative and qualitative methods, and draws on data extracted from a range of sources, including peer-reviewed journal articles, government statistical reports, private databases and documents from industry sources. A key source of data is the Bangladesh Integrated Household Survey (BIHS) conducted by the International Food Policy Research Institute in late 2011 (Ahmed 2013). The BIHS contains data on 5,503 households drawn from 64 districts in the seven primary divisions and is representative at both the national and divisional levels. The survey covers topics that are standard to most income and expenditure surveys in developing countries, as well as topics related to agricultural production, plot utilization, input use, and post-harvest management.

2.3 Background on Hybrid Technologies

The primary characteristic distinguishing hybrids from traditional varieties is heterosis (or hybrid vigor), which describes the increase in yield, uniformity, or vigor of cultivated plants that results from genetic contributions derived from the crossing of distinct parental lines. Its economic value lies in the fact that yield gains conferred by heterosis decline dramatically after the first generation of seed (F1), thus compelling farmers to purchase new F1 seed each season in order to continually realize these yield gains. This contrasts with conventional open pollinated varieties (OPVs) or self-pollinating inbred varieties (for rice), in which harvested grains can be stored and used as seeds in the following year.

This unique characteristic has been a driving factor behind investment in crop improvement for maize and several other crops. In the early twentieth century, public research on maize hybridization in the United States contributed to the development of a lucrative seed industry during the 1930s, including the entry of many small and medium-sized seed companies breeding and marketing hybrid maize seed to farmers. By the 1960s, almost all maize cultivated in the United States was grown from hybrid seed. Annually, maize receives more than US$1 billion in private research and development (R&D) investment in the United States—more investment than any other crop—owing largely to the incentives that hybridization provides to private breeders (see Fernandez-Cornejo 2004; Fuglie et al. 1996).

Hybrid maize cultivation has spread throughout much of the world, including into developing countries in Latin America, Sub-Saharan Africa, and Asia (Morris 1998). Hybrids of other crops, such as pearl millet, cotton, sorghum, and many vegetable crops, have also made inroads in developing countries (see, for example, Pray and Nagarajan 2010).

In spite of the benefits of hybridization to both breeders as well as farmers, there are substantial criticisms that are often raised regarding the suitability of hybrid seeds in developing country agriculture. First is the concern that seasonal or annual purchases of hybrid seed are too costly for many resource-poor, small-scale farmers in developing countries (Kuyek 2000). Several points are worth noting regarding this contention. One is that much evidence suggests that purchasing seed—both OPV (or inbred) and hybrid—is a fairly common practice among rice farmers in South Asia (Table 2.2), despite conventional narratives that argue otherwise. Data from the BIHS suggest that, although almost 45 percent of farming households in Bangladesh use saved seed, more than 75 percent purchase rice seed from private sources. This suggests that many farming households (more than 25 percent) use both saved seed and purchased seed simultaneously, and that a large percentage of farming households purchase rice seed from private sources. A related point is that although seed saving is an important crop management and livelihood strategy among the poor, it necessarily limits their access to technological improvements embodied in seed. Commercial seed markets are one among several mechanisms through which farmers can access these technological improvements—access that they might forgo if they were to depend solely on own-seed savings or exchanges with neighbors. A further point worth noting is that although hybrid rice seed is indeed significantly costlier than OPV rice seed (approximately 10 times the price), these costs are partly defrayed by a lower seeding rate.[2]

[2] Recommended seeding rates ranging from 15-30 kg/ha for transplanted hybrid rice, depending on agro-ecological conditions and other management practices. These seeding rates are generally substantially lower than rates for inbred rice. See Virmani, Siddiq and Muralidharan (1998) and Xie and Hardy (2009) for further discussion.

Table 2.2: Seed Replacement Rates for Different Crops in South Asian Countries

Crop	India, 2007 (%)	Bangladesh, 2007 (%)	Nepal, 2002 (%)	Pakistan, 2007-08 (%)
Wheat	25.23	26.46	28.5	17
Rice	25.87	24.74	11.1	34
Maize	44.24	97.97	9.2	32
Sorghum	19.87			
Millet	48.47			
Soybean	33.39			
Sunflower	62.88			39
Cotton	15.30			48

Note: Includes seed replacement rates for both open pollinated varieties and hybrids where applicable, such as for rice, maize, sorghum, millet, sunflower, and cotton.

Source: Seednet (2007) for India; BSGDMA (2007) for Bangladesh; ANZDEC Limited (2002) for Nepal; and Seed Association of Pakistan (2012) for Pakistan.

Second is the concern that hybridization leads to greater risk in the form of (i) lower in situ genetic diversity and greater susceptibility to pests and disease; and (ii) fewer management alternatives to cope with weather-related production risks. This latter concern is particularly relevant for smallholders with limited access to credit, insurance, and other services that help manage risk. Concerns over loss of genetic diversity can partially be offset by efforts to collect and catalog rice varieties, such as the International Rice Gene bank maintained by the International Rice Research Institute (IRRI), though these efforts primarily address global genetic diversity and do not directly address issues of in situ diversity. Additionally, there is the potential to incorporate both biotic and abiotic stress tolerance in hybrid rice, which may actually increase risk mitigation alternatives for credit- or insurance-constrained smallholders. The extent to which these factors are significant concerns is largely an empirical question that depends on context and situation.

A third concern is that hybridization concentrates market power in the hands of a few companies that are able to breed and market superior hybrids. Although compelling evidence suggests that seed markets for some crops are highly concentrated in some countries, and that farmer welfare may be adversely affected by corporate pricing strategies in certain instances, questions of market power are again essentially empirical, requiring careful and context-specific analyses of rice seed value chains. At present, the issue of predatory pricing behavior by monopolistic or oligopolistic hybrid producers is not a particularly troubling concern in Bangladesh, where a majority of seed is supplied by the Bangladesh Agricultural Development Corporation (BADC), a parastatal organized under the Ministry of Agriculture.

To summarize, despite criticisms of commercially marketed hybrid seeds for smallholders, the welfare trade-off between farmer-saved seed and farmer-purchased seed, as well as the externalities associated with lost biodiversity, are not as clear-cut as suggested. The specific opportunities, challenges, and risks associated with rice hybrids are discussed in more detail throughout this chapter.

2.4 Bangladeshi Experience with Hybrid Rice

The history of hybrid rice in Bangladesh is different from that in other countries in Asia. Although hybrid rice research began at the Bangladesh Rice Research Institute (BRRI) in 1993, it did not receive high priority on the public research agenda until after 2000. Rather, it was the private sector that took a lead in the introduction of hybrid rice, initially by importing seed from China to make up for shortfalls in domestic seed supply caused by floods in 1998-1999 (Table 2.3). Subsequently, several companies expanded beyond bulk seed imports to the importation of parental lines from China from which to initiate their own seed production in Bangladesh. Several firms have also invested in adaptive research and product development for hybrid rice, as has BRAC, a large non-governmental organization (NGO) and currently a leader in the hybrid rice seed market.

Table 2.3: Hybrid Seed Use and Share of Imports in Bangladesh, 1998-2007

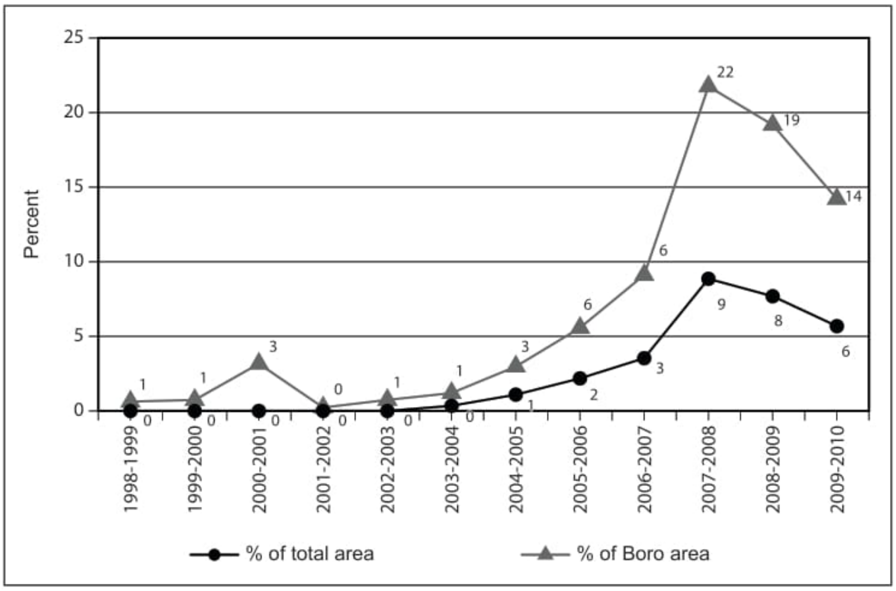
Year	Total seed used (metric tons)	Imported seed as a share of total seed used (%)
1999	150	100
2000	227	88
2001	320	67
2002	556	63
2003	803	77
2004	1,472	73
2005	2,935	77
2006	6,524	71
2007	10,026	77

Source: Hossain (2008).

Already, some companies are claiming success in expanding the hybrid rice seed market in Bangladesh. Advanced Chemical Industries Ltd. (ACI), a leading agricultural concern in Bangladesh, released Allok-93024 in 2003, a hybrid that can potentially compete with BRRI Dhan 29, one of the most popular inbred rice varieties in Bangladesh (F. H. Ansarey, Md. Shafiqul Aktar, and P. K. Bhanderi, personal communications, 2012). In addition, Bayer's latest hybrid releases are also reported to be (illicitly) making their way from India into the Bangladeshi market.

Despite the limited investment in research, hybrids represent a greater proportion of area under rice cultivation in Bangladesh than in neighboring India, despite India having more developed and well-funded hybrid rice research programmes. Hybrid rice cultivation in Bangladesh peaked in the 2007-2008 *boro* (winter) season—Bangladesh's main rice-growing season—at 22 percent of total *boro* cultivated area, or nine percent of all rice-cultivated area in the country (Figure 2.1). Hybrid rice cultivation has been mainly concentrated in Bangladesh's northern districts, particularly within the Rajshahi and Rangpur divisions (Table 2.4). This is largely due to liberalization policies that have increased the proliferation of small-scale irrigation equipment for use during the dry *boro* season (Kürschner et al. 2010).

Figure 2.1: Hybrid Rice Cultivation, Bangladesh, 1998-2010



Source: Ar-Rashid, Julfiquar, and Ali (2011), based on official figures.

Table 2.4: Hybrid Rice Adoption by Division, 2011

Division	Hybrid Rice Adoption Rate (%)
Barisal	0.00
Chittagong	6.02
Dhaka	5.35
Khulna	9.74
Rajshahi	16.08
Rangpur	15.34
Sylhet	5.62

Note: Figures represent the percentage of households cultivating land in each of the divisions that had cultivated hybrid rice from December 2010 through November 2011.

Source: Authors' calculation, based on data from Ahmed (2013).

Notably, Bangladesh has relied more on technology transfers in the form of hybrid rice seed and breeding material from China than it has on own, in-country R&D (see Arrashid, Julfiquar, and Ali 2011). This approach is significantly different from the one taken in other Asian countries such as India, where more concerted investments in public and private breeding have led to the homegrown development of rice hybrids for the Indian market. For countries such as Bangladesh, where public funding for research is limited and where few firms have the capacity to manage sufficiently large hybrid rice breeding programmes, the importation of hybrid material seems to be an attractive strategy.

However, there is some inherent risk in the strategy followed in Bangladesh. First is the risk associated with the distribution of seed that may be poorly adapted to Bangladesh's agro-ecological context, crop management practices, farming systems, and consumer preferences.[3] This last aspect appears to be especially troublesome for a heterogeneous product like rice grain, because grain not suited for the tastes and preferences of consumers often results in a thin output market and lower prices. Given higher seed costs (compared with conventional inbred varieties), higher

[3] As an example, in temperate Asia, such as Japan and China, sticky and soft rice is preferable. As such, japonica or indica/japonica hybrid varieties, which have generally low amylose content, are preferable, because these will result in grains that become soft and sticky during cooking (Kumar, Maruyama, and Moon 1994). In tropical South Asia, on the other hand, consumers prefer fluffier, non-sticky rice. Hybrids borne out of any combination with low-amylose japonica varieties (like those imported or derived from parental lines imported from China) will tend to result in grains that become soft and sticky during cooking, which consumers in those countries may perceive as being of lower quality.

expenditures on complementary inputs, and lower output prices, margins between returns and costs become increasingly narrow. We do not have adequate data to state unequivocally that this mechanism has contributed to the decline in area under hybrid rice cultivation in Bangladesh, but evidence consistent with this hypothesis does exist. Consider Table 2.5, for example, which reports farmers' perceptions about hybrid rice grain quality *vis-à-vis* grains from conventional inbred varieties. While a large share of farmers perceive that the hybrids have better appearance and aroma than the conventional varieties, only a relatively small share of farmers perceive that hybrid grain tastes better than the traditional varieties, that the stickiness of the hybrid grains after cooking is superior to that of traditional varieties, that the expansion of hybrid rice grain is superior to that of conventional varieties, or that the quality of hybrid grains can be maintained for an extended period. Some of the hybrids recently released by the private sector were designed to address some of these quality issues to make hybrid grain more comparable to other conventional *boro* varieties, such as the widely cultivated BRRI Dhan 29.

Table 2.5: Farmers' Perceptions about Quality of Hybrid Rice in Bangladesh

Quality/characteristic	Farmers reporting same or superior quality/ characteristic as compared with inbred rice (%)	
	2004	2005
Grain appearance	71	74
Taste of cooked rice	33	39
Stickiness of cooked rice	47	40
Aroma/smell	82	77
Expansion after cooking	49	45
Quality of cooked rice after long hours[a]	20	34

Note: [a] "Quality of cooked rice after long hours" relates to the taste and consistency of cooked rice when stored, cooled, and/or set aside after cooking.

Source: Azad, Mustafi, and Hossain (2008).

The second risk results from the volatile and sometimes unpredictable nature of trade policy: should Chinese exporters or Bangladeshi importers be unable to (or choose not to) ensure a continuous flow of germplasm from year to year due to tariffs, regulations, or other barriers imposed by either trading partner, then the benefits of hybrid rice cultivation could dry up quickly. Although this is not a pressing concern for either country at the moment, China's limited willingness to share its more advanced breeding lines and systems with other countries is an indication of just how significant trade barriers can be.

Studies from Bangladesh provide further insight into hybrid rice costs, returns, and adoption. In Bangladesh, hybrid rice is grown mainly during the dry (*boro*) season.[4] Even though annual yield variations have been recorded, hybrid yields are generally 15-30 percent higher than those of traditional inbred varieties (Azad, Mustafi, and Hossain 2008). Although farmers report some production cost reductions resulting from lower seeding rates and lower irrigation costs associated with early maturation, these savings are ultimately offset by higher fertilizer and pesticide use, further suggesting that the yield gains may be partly attributable to better management practices, in addition to the hybrid seed performance itself (Hossain 2008).

Azad, Mustafi and Hossain (2008) also find that adoption rates are high among small farmers (less than 0.5 hectare farm size) in 2004; in the subsequent year, however, adoption rates have increased among large farmers (greater than 2.0 hectare farm size) and medium farmers (0.5-2.0 hectares). Despite growing adoption, farmers initially faced lower market price for both grain (4-5 percent lower than varieties during the 2004 and 2005 seasons) and straw (nine percent lower than varieties in the 2007 season). Eventually, the grain price for hybrid rice did exceed the price for a competing inbred (BRRI Dhan 29)—by four percent in 2007—indicating that better hybrids, greater consumer/miller acceptance, or improved on-farm management practices may have entered the equation. Despite growing evidence of hybrid rice's profitability in Bangladesh, the adoption rate of hybrids is still low, at four percent (Azad, Mustafi and Hossain 2008). The benefits of higher yields, higher tillering ability, shorter maturity, and increased lodging resistance seem to be offset by higher seed price, higher expenditures on other inputs (such as fertilizers and pesticides), poor cooking quality reflected in lower output prices, and high pest and disease susceptibility in Bangladesh.

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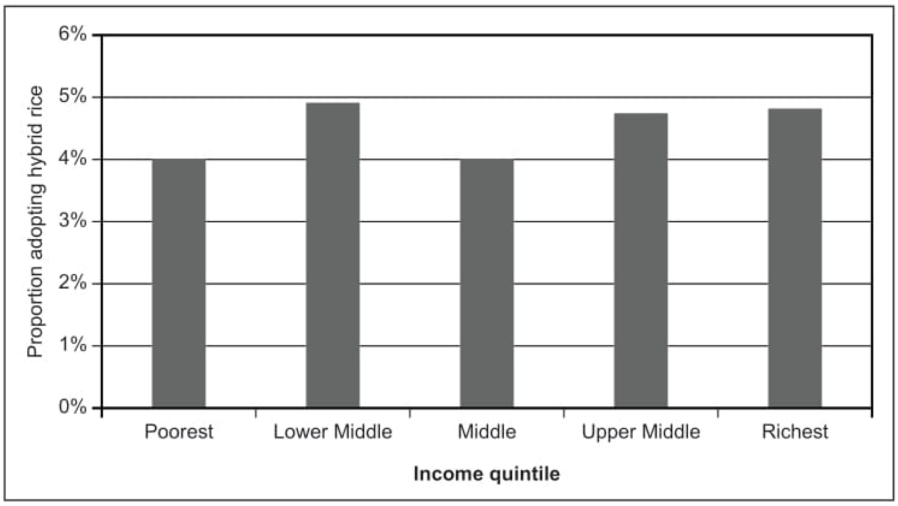
4 This is somewhat a consequence of history. Hybrids were first introduced in Bangladesh during the 1999 *boro* season, after the government allowed the importation of 2,000 metric tons of hybrid seed following a 1998 flood that had destroyed a large volume of rice seeds (Azad, Mustafi and Hossain 2008). Since then, most of the hybrids and other high-yielding varieties that have been distributed in Bangladesh have been *boro* varieties. In addition, the proliferation of shallow tube wells for irrigation has made it much more affordable to cultivate rice during this dry season, which has led to dramatic increases in the volume of land under rice cultivation during the *boro* season. Consequently, this also implies that enhancements to hybrid varieties to improve tolerance or resistance to most abiotic stresses will be of limited value to Bangladeshi farmers, because the most serious abiotic stresses.

These analyses are limited insofar as they examine adoption from an *ex post* perspective. In addition, they provide limited characterization of adoption patterns disaggregated by socioeconomic characterizations. Azad, Mustafi and Hossain (2008) surveyed farmers in 2004 and 2005 on their planned use of hybrids in the following years (2005 and 2006 respectively) and disaggregated the responses by farm size, age and education. Although their study finds no discernible pattern regarding adoption patterns based on farm size, it does find that younger and more educated farmers seemed more eager to cultivate hybrids.

Data from more recent and nationally representative BIHS, on the other hand, suggest that farmers with larger landholdings are significantly more likely to adopt hybrid rice than farmers with either medium or small landholdings. Specifically, BIHS suggests that poor households (those households with per capita incomes lower than US$1.25 per day, adjusted for inflation and differences in purchasing power) are less likely to adopt hybrid rice than nonpoor households. Rather ironically, it also suggests that households that have adopted hybrid rice do not, on average, have significantly higher incomes than those households that have not adopted. According to these data, there does not appear to be any significant statistical relationship between higher income and a higher adoption rate for hybrid rice (Figure 2.2 and Table 2.6).

Figure 2.2: Hybrid Rice Adoption in Bangladesh by Income Quintiles, 2011



Source: Authors' calculations, based on data from Ahmed (2013).

Table 2.6: Hybrid Rice Adoption in Bangladesh by Income Quintiles, 2011

Income quintile	Adoption rate (%)
Poorest 20%	4.00 (0.196)
Lower middle 20%	4.91 (0.216)
Middle 20%	4.00 (0.196)
Upper middle 20%	4.73 (0.212)
Richest 20%	4.82 (0.214)

Note: Standard deviations are provided in parentheses. No statistical significance is found based on one-tail t-tests of group adoption rates among adjacent income groupings at 1 percent, 5 percent, or 10 percent levels.

Source: Authors' calculation, based on data from Ahmed (2013).

In Rajshahi and Rangpur divisions, however, where hybrid adoption rates are highest, some evidence exists that suggests household incomes are higher for hybrid rice adopters than for those households that have not adopted (though the income difference is only marginally significant in the Rajshahi sample). It should be noted that Rangpur division has the lowest per capita income among all of Bangladesh's divisions; thus, if hybrid rice cultivation does lead to higher incomes in Rangpur, increased hybrid rice adoption may prove a viable pathway for addressing poverty alleviation. For the country as a whole, however, fewer than 60 percent of hybrid rice adopters had incomes above the poverty line.

2.5 Future Scenarios and Challenges for Hybrid Rice

Despite recent declines in hybrid rice cultivation in Bangladesh, interest in the technology remains high. Yet there are significant technical and economic challenges related to hybrid rice in Bangladesh and South Asia more generally. Because of its potential for boosting stagnant yield growth, improving national food security, and raising incomes, hybrid rice remains high on the agenda of many public policy makers and corporate decision makers. Additionally, the sustainable intensification of rice production on a smaller area of land allows for greater diversification into other, higher-value crops. This section analyses the key challenges associated with hybrid rice in Bangladesh and the broader context of South Asia. To analyze these challenges, we draw on the conceptual framework described earlier. In particular, this section focuses on key constraints related to investment, collaboration, and risk management strategies associated with the stages of discovery, development, and delivery.

Scientific Discovery

The challenges surrounding the expansion of hybrid rice in Bangladesh begin at the discovery stage, which is characterized primarily by the fundamental scientific and technical dimensions of the technology. These challenges represent broad classes of problems that are generally addressed over long-time horizons and at a pre-commercial, pre-regulatory, and pre-distribution stage. We examine some of these constraints (for details, see Xie and Hardy 2009).

First, researchers have been severely challenged in their efforts to secure high levels of heterosis in hybrid rice. China has succeeded in achieving high levels of heterosis, but only for hybrids suitable in temperate regions. Much of South Asia, including Bangladesh, requires tropical hybrids, in which heterosis is only 10-12 percent over the best modern inbred varieties. One of the most important factors conditioning varietal selection is the relative yield advantage of one variety *vis-à-vis* another. In South Asia, tropical rice hybrids are not yet providing a yield gain that is attractive enough to induce farmers to switch on a large scale. An argument can easily be made that better management practices (such as early transplanting, optimal spacing, etc.) in the cultivation of inbred rice varieties—many of which also have attributes such as pest and disease resistance that are superior to the current generation of hybrids in South Asia—can generate comparable yield gains.

Second, researchers have been constrained by the limited effectiveness of the hybridization systems currently in use—in particular, the three-line male sterility system that is most commonly used in South Asia, but also the more advanced two-line system that is used in China. Further development of hybridization systems based on tools of genetic modification and (possibly) chemical hybridizing agents could accelerate hybrid rice research in the long run. In the short run, however, hybrid rice research will still depend on complex and sensitive systems of hybridization for rice.

Third—and of possibly less importance today than a decade ago—is the narrow germplasm base from which hybrid rice research is being conducted, which is in part a result of the limiting reliance on the male sterility system and in part a result of the absence of an effective heterotic genetic pool. This narrow base constrains the efficiency and output of hybrid rice breeding programmes and, further down the line, creates high levels of pest and disease susceptibility in cultivated hybrid rice populations. Because of the lack of commercially usable cytoplasmic male sterile lines, development of hybrid rice outside China has been slower than expected (Virmani 1994), which poses difficulties for breeding hybrid rice with improved abiotic and biotic stress tolerance traits, better adaptation to different agro-ecological contexts, and better cooking and consumption qualities. Efforts to expand this narrow germplasm base are also hampered by China's implicit ban on the export or exchange of its most advanced materials for hybrid rice breeding, including female parental lines used in its superior two-line breeding system. That said, the narrow genetic diversity of female parents that plagued earlier generations of hybrid rice in South Asia is no longer viewed by researchers as the key issue, having been resolved by the creation of new female lines and new techniques for creating such lines.

Fourth, and related to this narrow germplasm base, has been the poor grain quality of hybrids, which initially led to low levels of consumer acceptance. This issue was of particular importance to farmers in high-productivity irrigated areas, who produce marketable surpluses, though possibly less so for farmers in rainfed or otherwise low-productivity areas, who produce primarily for their own consumption. Low consumer acceptance of hybrid grain implies a lower quantity demanded, which results in a lower market price for hybrid grain than, e.g. grain from traditional or modern inbred varieties. This appears to be particularly problematic in Bangladesh, due to the importation of hybrid materials from China. It is less of a concern in India, for example, where hybrid research has led to homegrown solutions. The key issue is amylose, the starch molecule that gives milled rice its specific appearance and character after cooking.[5] Although there is significant variation in consumer preferences for cooked rice across South Asia, higher amylose content (above 25 percent) is broadly reflective of generalized preferences in the region. In the past several years, researchers have been able to address this constraint, though cultivation of hybrid rice with these improved qualities is still reportedly at relatively low levels.

Most scientists agree that the current stock of scientific and technical knowledge is at a level at which many of these problems can be readily solved with sufficient time, effort, and resources. But given the time lag between research investment and product delivery, and potentially thin markets—at least initially—this also suggests that solutions will not be immediately available or remunerative in commercial markets. Thus, there is a need for both public and private investment in hybrid rice.

As with most crop research—including other hybrid crops that are potentially lucrative in downstream markets—an optimal level of upstream

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5 Higher amylose content (20-25 percent or more) gives cooked rice a high volume and dry quality with well-separated grains, whereas lower amylose content (below 20-25 percent) gives cooked rice a moister, stickier quality (IRRI 2012).

public investment is required to translate the science into a viable technology. Public investment in R&D is generally more adept at solving basic problems constraining the effective use of a technology where longer time horizons and pre-commercial application are key characteristics. In addition, where neither private firms nor sovereign governments are willing to invest in removing these constraints—where the public good is global rather than country-specific in nature—there is a case for international public investment in R&D efforts.

The international donor community, notably Asian Development Bank (ADB) and Food and Agriculture Organization of the United Nations (FAO), has financed hybrid rice R&D at IRRI, which began its research programme on hybrid rice for tropical Asia in 1979. In 1988-1989, IRRI released two cytoplasmic male sterile lines, IR58025A and IR62829A, which are still used in most hybrid rice breeding programmes in Asia today. Large-scale testing of hybrids developed from these lines followed in 1998, followed by the commercial release of hybrids in India (*Sahyadri* and CORH 2), Philippines (*Mestizo*), and Vietnam (HYT-57), among other countries.

In 2008, IRRI widened its commitment to hybrid rice research by establishing the Hybrid Rice Development Consortium (HRDC), a global platform designed to support research and share materials with public research agencies, private seed companies, and civil society organizations. Between 2005 and 2010, IRRI transferred more than 7,400 germplasm samples to other hybrid rice researchers around the world, with more than 70 percent of those transfers moving through the auspices of HRDC. Germplasm transfers have increased dramatically in recent years, with more than 80 percent of total transfers occurring from 2008 through 2010. Notably, less than 5 percent of IRRI's total germplasm transfers have gone to Bangladesh, largely reflecting Bangladesh's heavy dependence upon material and seed transfers from China. This contrasts starkly with transfers to India. Material transfers to India represent 33 percent of all transfers between 2005 and 2010, though 61 percent of the total germplasm transfers to India occurred during 2010.

IRRI has further expanded its commitment to hybrid rice research under the Global Rice Science Partnership (GRiSP), with a planned investment estimated at US$15-17 million for South and Southeast Asia over five years; this figure does not include the related rice breeding work undertaken in other GRiSP components nor other IRRI programmes that also support hybrid rice research or investments made by national partners.[6] In addition, although national research organizations have made limited investments in hybrid rice to date (Table 2.7), they remain a necessary long-term complement to IRRI's research.

Table 2.7: Research and Development of Hybrid Rice in Asia, Selected Countries

Country	Research initiated	First hybrid rice released (number of releases)
India	1989	1994 (20)
Bangladesh	1996[a]	1999 (4)[b]
Vietnam	1992[a]	1992 (7)
Philippines	1993	1993 (3)

Note: [a] The first hybrids released in Bangladesh were imports from China and India; the first hybrids released in Vietnam were imports from China. See Janaiah, Hossain, and Husain (2002).

[b] According to Azad et al. (2008), hybrid rice research in Bangladesh was initiated in 1993 but only gained momentum in 1996.

Source: For research initiated: India: IRRI (2005); Bangladesh: IRRI (2005); Azad, Mustafi, and Hossain (2008); Vietnam and Philippines: Janaiah and Hossain (2003); for first hybrid rice released: India: DACNET (2007); Janaiah, Hossain, and Husain (2002); Bangladesh, Vietnam, and Philippines: Janaiah, Hossain, and Husain (2002); and Janaiah and Hossain (2003).

Arguably, hybrid rice research has suffered from donors' short-term outlooks and project funding cycles. Although some resources were allocated to public-sector research at both the national and international levels, there is a sense among many scientists that a large portion of the funding and scientific effort was allocated to capacity strengthening, demonstrations, and dissemination activities, all built around a limited set of hybrids and hybrid parent lines. In short, these funding commitments likely impeded early and rapid progress in addressing the technical challenges outlined above. This suggests a role for private sector investment

[6] GRiSP's long-term goals aim at the adoption of new hybrid rice with at least a 15 percent yield advantage. Specific GRiSP milestones for hybrid rice are as follows: 50 new breeding populations developed and distributed to partners in South and Southeast Asia by 2011; 5,000 new hybrid parents and hybrids test-crossed and evaluated at IRRI and other locations in South and Southeast Asia by 2013; and 10 new hybrids released for commercial production by public- or private-sector partners in South and Southeast Asia in 2015. Budget estimates are for both Southeast and South Asia based on an assumption that hybrid rice is allocated an equal (17 percent) share of funding allocated to the six subthemes under Theme 2: "Accelerating the development, delivery, and adoption of improved rice varieties." See IRRI, AfricaRice, and CIAT (2010).

in hybrid rice research, though private-sector funding of research on these upstream issues is unlikely to fill the funding gap: while private investment has been central to problem solving in the South Asian market, but such private investment in hybrid rice research is paltry compared with private investment in maize research.

Despite the constraints imposed by insufficient investment and expenditure on hybrid rice research, the collaboration strategies being formed around hybrid rice are worth noting. IRRI's HRDC is a critical platform for collaboration between public research agencies and private seed companies on various aspects of hybrid rice research. IRRI's long-standing relationship with pivotal agencies in China's national agricultural research system is also a critical input to making expertise and materials available to consortium members and IRRI's partners. In addition, IRRI's forward-looking policies on intellectual property and public-private partnerships provide an avenue for supporting effective collaborations with firms that are willing and able to invest in hybrid rice. Although more rigorous evaluations of these various collaboration strategies are needed, there are strong indications of a relevant architecture for translating hybrid rice science from the public sector into viable hybrid rice technologies in the private sector.

The risks associated with hybrid rice research at the discovery stage pertain largely to the state of the science. One such risk is related to the long-term value of hybrid rice as a practical platform for launching genetically-modified (GM) traits in rice. Hybrid rice, like other hybrid crops, provides innovators with a biological form of intellectual property rights (IPR) protection, because farmers have to purchase seed each season to realize the yield gains conferred by heterosis. Not only does this allow innovators to recoup their R&D investments in rice improvement, but it also creates an effective platform for continuous investment in developing GM rice traits, much like the experience in the hybrid and GM hybrid maize market in North America. Moreover, because firms can easily monitor their sales of hybrid rice seed, they gain a means of monitoring farmers' trait preferences, on-farm performance, and crop management practices, thus providing vital informational feedback mechanisms needed to support continued improvements and effective stewardship. However, the risks associated with the nascent or controversial biosafety regulations in some developing countries can limit the realization of this long-term value in hybrid rice.

Technology Development: Solutions to the scientific and technical problems discussed earlier would encourage more serious investment by the private sector in hybrid rice product development. However, product development itself faces several key challenges that need to be addressed if hybrid rice is to generate welfare-improving and yield-enhancing impacts in Bangladesh or more generally throughout South Asia.

A major difficulty facing hybrid rice is the production of high-quality hybrid seed. Technical requirements for hybrid seed production are sensitive, requiring careful management of breeding materials and the seed farms themselves. Unlike varietal rice, it is difficult to outsource hybrid rice seed production to smallholders, smallholder cooperatives, or community and village seed production schemes. The technical requirements for hybrid rice seed production represent a costly constraint on the production of marketable quantities of seed for all but the largest, most technically advanced, or well-capitalized seed companies in the market.

A second hurdle related to seed production is the protection of the intellectual property embodied in the seed. Private investment in seed-based technologies is partly determined by the existence of a credible IPR policy regime. Although hybrids provide breeders, seed companies, and entrepreneurs with a biological form of IPR protection, these biological IPR protections are more effective when backed by some form of legal protection. This is particularly valuable in situations where it is easy for competitors to steal parental lines from foundation seed and production fields, as is the case in both industrialized and developing countries. By ensuring that innovators have legal recourse allowing them to appropriate a portion of their innovation rents, plant variety protection (PVP) laws can incentivize private investment in hybrid rice development. In addition, through related requirements of disclosure, certification, and labeling, PVP laws can help address information asymmetries between farmers and seed retailers. Unfortunately, few South Asian countries have sufficiently credible PVP laws. India's Protection of Plant Varieties and Farmers' Rights Act of 2001 provides the region's highest standard of protection, but other South Asian countries lag behind in this regard.

An additional regulatory issue emerges around the issue of competition and industry concentration. In most South Asian countries, the formal rice seed market is largely concentrated around the high-volume, low-margin varietal end of the business and is not what might be termed *cutting edge* in the seed industry. Only a few firms have entered the high-value, high-potential segment of the market with hybrid rice seed. With such a small number of companies in the hybrid seed market, there are concerns that large companies operating in highly oligopolistic conditions will be able to exert a high degree of market power over farmers—including small-scale, resource-poor farmers. This concern is often voiced in India—even though the hybrid rice market there is host to a fairly large number of companies

(Spielman et al. 2011)—and in other countries such as Bangladesh where the market is much thinner. Continuous and careful analysis of market conditions, including competition and concentration, backed by effective enforcement of antitrust laws are necessary to ensure that seed markets remain competitive.

The risk management issues of using hybrid rice as a platform for transgenic traits become more acute when considered at the product development stage. Risks are associated with individual traits conferred on hybrid rice (such as insect resistance or drought tolerance), stewardship of transgenic hybrid rice lines, gene flow issues to wild relatives, pollen flows to other rice varieties such as high-value *basmati,* and other such concerns. The biosafety policies and systems needed to assess and manage these risks are nascent in most South Asian countries and are the source of extensive public scrutiny and discourse. Opaque regulatory environments may significantly affect private-sector decisions on investment in transgenic traits, so creating a transparent regulatory environment to address these issues is therefore critical to the commercialization of hybrid rice containing potentially beneficial GM traits.

Product Delivery

Product delivery is possibly the weakest element in the hybrid rice innovation process. Despite accounting for 22 percent of total *boro* cultivated area as recently as 2007-2008, area under hybrid rice cultivation has steadily declined in the ensuing years. Concerns over seed quality and general perceptions of poorer grain quality *vis-à-vis* traditional varieties have no doubt contributed to this decline, with the latter largely due to the importation of seeds and genetic material poorly suited to end consumers' tastes and preferences.

Ultimately, the successful delivery and large-scale adoption of hybrid rice will depend on improvements made in the upstream discovery and development stages. Although hybrid rice has immense potential for increasing productivity and improving overall welfare for the poor in Bangladesh, the challenges are not insignificant. Important challenges include increasing both seed and grain quality and customizing varieties to various agro-ecological conditions and consumer preferences. Addressing the challenges of grain quality and customizing hybrids to consumer preferences have important implications for the output prices that farmers receive for their grains. At present, the price penalty on hybrid rice at the farm gate places it at 10-20 percent less than coarse grain rice in Bangladesh. Although breeders have made progress in increasing amylose content through conventional breeding efforts with better germplasm and molecular markers, the new hybrids coming on the market will need to overcome this price penalty to encourage adoption. The feedback mechanisms between the delivery stage and the discovery and development stages can facilitate these improvements. Further research is required to better understand the factors that motivate or constrain farmers' adoption of hybrid rice. Understanding these factors will help not only inform future discovery and development, but will also provide insight into potential policy responses that can speed up the widespread adoption of hybrids.

2.6 Conclusions and Policy Recommendations

This chapter examines the processes and policies that encourage effective public and private investment in hybrid rice benefiting poor farmers in Asia, with a specific emphasis on the context and experiences of Bangladesh. The study identifies the roles of various organizations involved in advancing hybrid rice development and delivery and examines alternative incentives for enhancing the level and effectiveness of public and private investment in hybrid rice discovery, development, and delivery.

There is an immense stock of scientific knowledge and expertise on hybrid rice. Although much of this stock resides in China, high-quality expertise and accumulated experience also exists within the international agricultural research system, among multinational and domestic firms in the private sector, and in public research organizations in other Asian countries. More important, many of these actors are closely linked through a variety of scientific, professional, and product-related networks.

Several policy innovations could accelerate the discovery, development, and delivery of hybrid rice technology in Bangladesh. First and foremost is the recommendation for further public investment in the upstream research on hybrid rice to develop the tools and technologies needed to advance hybrid rice. While Bangladesh has heretofore relied heavily upon imported seeds and genetic materials from China, a more concerted effort in promoting a domestic hybrid rice development program may ultimately be successful in bringing to market hybrids that are more suited to consumers' tastes and preferences. International and national funding for public research that addresses improved hybridization systems, grain quality, adaptation of hybrids to local agro-ecological conditions, and germplasm diversity can provide the platform for more applied plant breeding to develop improved hybrids by both the public and private sectors.

Second is the need to improve the innovation incentives that may ultimately encourage more private investment in hybrid rice development—that is, policies and institutions needed to encourage investment in hybrid rice by public research organizations, private firms, and farmers themselves. Stronger IPR policies and enforcement could encourage the entry of complementary private investment, while other policy incentives could accelerate the dissemination and commercialization of public research on hybrid rice that is sitting on the shelf or otherwise confined to academic use.

At the delivery/adoption end of the spectrum, careful thought needs to be given to the use of public resources to subsidize hybrid rice seed and complementary inputs. Although subsidies have strong historical precedence in encouraging the adoption of new technologies in South Asia, such interventions may ultimately work against widespread adoption and the growth of a competitive hybrid rice seed industry. South Asia's experience with input subsidies suggests that price distortions can lead to rent-seeking behavior and elite capture among certain types of farmers and industries, thus impeding market growth and efficiency in the long run.

In summary, hybrid rice has the potential to transform rice cultivation in Bangladesh despite significant challenges. The basic outcome of stable, better adapted, and commercially accessible hybrid rice could translate into a range of positive impacts: enhanced rice productivity; increased on-farm incomes for smallholders; and reductions in land required for intensive rice production, which in turn allows for reallocation to other agricultural and non-agricultural activities. Significant scientific, technical, and policy challenges exist at each stage of the innovation process—discovery, development, and delivery—and repeated iterations of research and development need to be pursued. The ability of public policymakers, corporate decision makers, scientists, entrepreneurs, and farmers to understand these challenges and anticipate solutions is fundamental to the long-term success of hybrid rice in Bangladesh.

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