Bangladesh Agricultural
Research Vision 2041

Bangladesh Agricultural Research Council
New Airport Road, Farmgate, Dhaka-1215, Bangladesh
www.barc.gov.bd

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Publication: 14
Bangladesh Agricultural Research Vision 2041

Printed
February 2023

Published by
Project Implementation Unit (PIU)
National Agricultural Technology Program-Phase II Project (NATP-2)
Bangladesh Agricultural Research Council (BARC)
Dhaka-1215, Bangladesh

Minister
Ministry of Agriculture
Government of the People's Republic of Bangladesh

Message

Agriculture is functioning as a catalyst since long for sustainable development and growth of the Bangladesh economy. Unfortunately the country's natural resources are progressively being degraded as a result of concerted occurrence of natural disaster, population growth, inappropriate farming activities, and other human interventions. Besides, low productivity, genetic erosion, huge post-harvest loss and poor agro-processing, scarcity in quality seed/breed, high feed cost, and inadequate market intelligence system are some of the key challenges. Growth of all the three farm subsectors viz. crops, livestock and fisheries are constrained by these challenges. For ensuring nutrition security the subsectors shall be equally emphasized by outlining pertinent research issues with appropriate strategies. Thus, innovations and adaptation of climate smart technologies seemed as a major concern of scientists and policy makers to address the global warming bound difficulties and productivity deadlock to revitalize commercial agriculture.

I am happy to learn that Bangladesh Agricultural Research Council has taken concerted efforts of producing Bangladesh Agricultural Research Vision 2041 for all the three subsectors. I firmly believe and feel that this document will serve as a valuable guide in undertaking appropriate research towards the country's sustainable agricultural development under prevailing and anticipated opportunities and risks that emerge from the interface among water, climate change and human activities.

I extend my heartiest compliments and felicitations to those persons who paid tireless efforts in preparing this invaluable document.

Joy Bangla, Joy Bangabandhu
Long live Bangladesh

Dr. Muhammad Abdur Razzaque, MP

Secretary
Ministry of Agriculture
Government of the People's Republic of Bangladesh

Foreword

Bangladesh has achieved a remarkable progress in agricultural production which includes crops, livestock and fisheries. The main drivers of which are agricultural policy reforms and agricultural technological innovations. Nevertheless, the present transformation is threatened by numerous challenges such as increasing population, declining arable land, land degradation, declining soil fertility, shrinkage of quality water, rapid urbanization and climate change. Thus, the situation of increasing food production on decreasing arable land claims for a strong agricultural research. To enhance and sustain agricultural productivity, strategic plans and programs are essential. I understand that the vision document has considered all these issues.

Under the perspective, Bangladesh Agricultural Research Council (BARC) has taken up a novel initiative to produce a vision document, Bangladesh Agricultural Research Vision 2041. I came to realize that the foremost purpose of this document is to generate sustainable technologies through undertaking demand-driven research as to enhance agricultural productivity (crops, livestock and fisheries) and diversification, farmer's income, nutrition security, efficient natural resources management, improved marketing system and employment opportunities. It is a reality that the country is highly vulnerable due to climate change which causes salinity, floods and drought. Thus, effective plans and programs are needed to address climate risk and climate adaptation among others, negating growth in all the sub-sectors. There is also a great need to conserve natural resources so that short-term exploitative measures do not jeopardize long-term farm productivity.

The present food production growth rate cannot be sustained without technological breakthrough following an appropriate research vision, which is vitally needed to shift the yield frontier through advanced breeding and improved management technologies to ensure a competitive production system.

Finally, I would like to appreciate Dr. SM Bokhtiar, Executive Chairman, BARC and Dr. Md. Harunur Rashid, Director, PIU-BARC, NATP-2 and his team for preparing a country-need document for designing global standard research vision in all branches of agriculture. I believe and wish that this document would serve as an excellent guide for the current and future researchers to plan research programs to wipe out hunger and malnutrition towards building a smart Bangladesh by 2041 as dream of the present government.

Joy Bangla
May live Bangladesh forever

Wahida Akter

Executive Chairman
Bangladesh Agricultural Research Council

Preface

It is implicated that the long waited dream of the Father of the Nation, Bangabandhu Sheikh Mujibur Rahman, Sonar Bangla (Golden Bangla), constitutional plight for food security and present governments' pledge of building Smart Bangladesh and Transformed Bangladesh by 2041 a developed country would not happen but necessitate a newly translated Bangladesh Agricultural Research Vision 2041 under the changing farm sector, circumstantial perspectives, increased quality food demand and natural resource dwindling situations. By this time, a good number of policy and strategic documents has been adopted by the government wherein agricultural research vision has not been delineated in particular, rather in most cases as general and unspecified agenda. In parallel, a huge trade gap in farm products is a reality for many years despite of significant accomplishment in the sector, compelling to design a novel revelation in agricultural research appropriate to upsurge productivity and eradicate or at least minimize the gap and reducing import bound expenses. Creation of employment opportunities, income generation and keeping youth and women in the sector as a decent profession are inimitable challenges to be diligently resolved by agricultural commercialization through novel innovation following a competent vision.

Considering the scenarios, PIU-BARC, NATP-2 has undertaken a hectic initiative of preparing a timely needed far-reaching Bangladesh Agricultural Research Vision 2041 combining both top down and bottom up approaches. To revert present and future farm challenges, ten strategic objectives viz. improve agricultural productivity, enhance nutrient rich and safe food production, improve harvesting, value addition and food processing, improve access to genetic material, information and knowledge resources, improve risk management, smart integrated farming systems, improve and maintain the quality of natural resources, robust technology delivery system, human resources development (HRD) and commercialization of agricultural technologies are proposed together with a quite number of approaches. With all these proposed endeavors the existing dire problems would be transformed into due potentials.

I presume that the key thematic research areas and meaningful strategies are diligently being incorporated in the vision document. This would be a good guide for future researchers, policy makers, and donors towards building a pulsating and thriving farm sector, consequently, a climate smart, nutrition sensitive and competitive farm sector would be visualized.

I concede and recognize all who worked hard for bringing such a precious document in light.

Joy Bangla
May live Bangladesh forever

Dr. Shaikh Mohammad Bokhtiar

Director
Project Implementation Unit
National Agricultural Technology Program Phase II Project
Bangladesh Agricultural Research Council

Prologue

Adoption of farm-friendly policies and undertaken time bound action plans, innovations, budget allocations, production support followed by appropriate implementation have eased Bangladesh agriculture to achieve a significant success in all the three sub-sectors (crops, livestock and fisheries) as manifested in sufficiency in fishes, meat, egg and in most food crops except pulses and oilseeds. However, its farm sector is striving best from innumerable challenges like climate change netted catastrophes, productivity ceiling, insufficient farm growth, dwindling natural resources, high post-harvest loss but poor agro-processing, adoption lag, inadequate market system etc. On the contrary, there prevails opportunities like crop diversification value addition and product diversification, agro-processing, and commercialization, creating employment opportunities, subsiding yield gap etc.

The prevailing challenges and opportunities in the farm sector are unique in nature but highly complicated interfacing with climate change, natural resources and human interventions, requiring a novel research direction coupled with harnessing potentials of cutting edge sciences and technologies. Concurrently a low carbon growth and competitive skill based competence oriented research vision toward safe and sustainable and commercial production system is inevitable for promoting expected farm growth in context of present and future perspectives. Such dares effort is not believed to be accomplished with the existing vision document published by Bangladesh Agricultural Research Council (BARC) in 2011.

Under these perspectives the Project Implementation Unit of BARC with fund support from National Agricultural Technology Program Phase II undertook an initiative to prepare Bangladesh Agricultural Research Vision 2041. This exertion has been carried out by combining both top down and bottom up approaches after holding regional workshops at eight division and a series of stakeholders and validation workshops. In preparing the vision document all the three farm sub-sectors has been critically reviewed and pertinent research areas have been integrated. This will facilitate and guide our researchers in undertaking appropriate research for a viable farm growth ensuring food and nutrition security toward transforming Evergreen Revolution instead of mere so-called Green Revolution.

I duly acknowledge for the support offered by Dr. Shaikh Mohammad Bokhtiar, Executive Chairman, BARC in all the way journey. My sincere thanks and gratitude are due for my colleagues and team members at BARC and elsewhere who took enormous labor and patience in capturing the ideas from the bottom level and guidelines from the policies and plans.

I am confident enough that with the proposed research endeavors the existing formidable problems would be transformed into due potentials turning the country a developed one with a vibrant farm sector.

Joy Bangla
May live Bangladesh forever

Dr. Md. Harunur Rashid

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INTRODUCTION

Background

Agriculture is the mainstay for sustenance of Bangladesh economy with a splendid role in increasing productivity and income and bringing rural peoples' prosperity. The sector has been one of the key drivers for accelerating national growth, pastoral development and poverty reduction. There is a colossal pressure on agricultural sectors (crop, livestock and fisheries) to deliver food for 165.16 M people using 16.06 M ha total cropped area and 8.12 M ha net cropped area (BBS, 2022). Agriculture has brought an overwhelming impact at multifarious dimensions on job creation, poverty alleviation, food and nutrition security and various economic and social advantages. The country's labor-intensive farming has achieved steady growth in crops, livestock and fisheries despite experiencing often climate bound intricacies. However, a slow sectoral growth, as occasionally noticed, has consequently resulted in poor performance of the national economy due to huge import at the cost of hard earned foreign currency reserve.

Although, the share of agricultural sectors in GDP to the country has declined over time (Fig.1) as a result of ongoing structural adjustment process, but its absolute value is increasing, and its economic and socio-political significance in terms of export earnings, employment and food security remains undeniable. These sectors are the principal suppliers of raw materials for agro-based industries and except readymade garments, a large part of the manufacturing sector relies on the processing of agricultural commodities (e.g. jute, tea, sugarcane, hides and skin shrimp, rice and wheat). Bangladesh is one of the top producers of rice, potatoes, tropical fruits, jute, and farmed fish. Although rice and jute are the primary crops, wherein maize and vegetables are assuming greater importance. Maize is occupying large areas day by day with current production near about 6.0 million ton (M t) (www.moa.gov.bd).

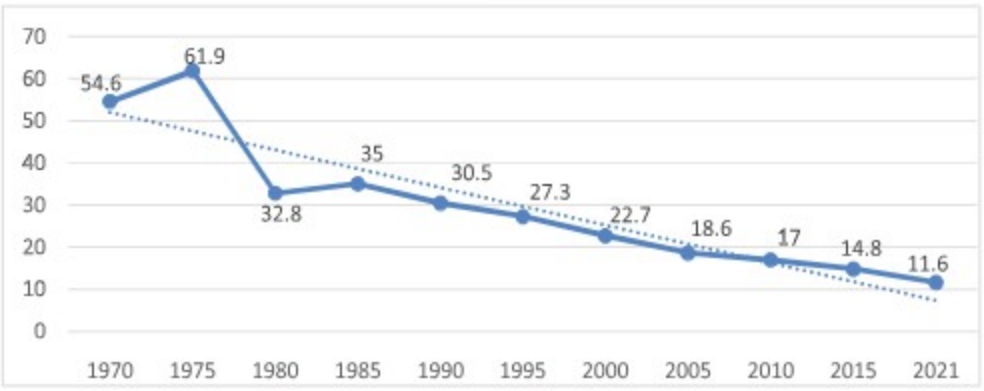

Fig. 1. Agricultural share of GDP (%) during 1970-2021 (The World Bank, 2022)

Livestock are the pivotal source of premium quality proteins essential for a healthy life. These are irreplaceable assets playing an indispensable role for building rural peoples' livelihood. About 70-80% of the total livestock produce is contributed by landless, marginal and small farm families. Its rearing can provide a pathway for alleviating poverty through improvement of family nutrition, cash income, asset building and women employment. More than 70% rural folk keep animals, which holds security and income from livestock accounting for 30-40% of total farm income. The contribution of livestock to the national GDP (Constant Prices) is 1.90% in 2020-2021 with GDP growth rate at 3.10% (Constant Prices) and its share to Agricultural GDP (Constant prices) is 16.52%. Per capita per day availability of animal protein like milk and meat rose to 208.67 ml/day and 147.84 g /day, respectively, and egg to 136.01 no/year in 2021 (BBS 2021). Approximately, 20% - 50% of the people are engaged directly and indirectly in the sector (www.dls.gov.bd).

Bangladesh is one of the world's leading fish producing countries with 4.62 M t fish production in FY 2020-21 and aquaculture accounts for 57.10% of its production. It has exceeded the projected fish production target of 4.6 M t by 2020-21 in conformity with the targets of the Vision-2021. The country is self-sufficient in fish, supplementing about 60% (with per capita of 62.58 g/day against targeted per capita of 60 g/day) of total daily animal protein intake. This subsector earns a considerable amount of foreign currencies by exporting fish, shrimps and other fishery products that accounts for 1.39% of total national export earnings (EPB, 2022). Bangladesh ranks 3rd in inland open water capture production, 5th in aquaculture production, 2nd in average fish production growth rate, 4th in Tilapia production, and 1st among 11 hilsa producing countries. As a single species hilsa fish has been making the highest contribution (12.23%) to the country's total fish production. The GDP growth in fisheries sub-sector is 2.08 % and its contribution to overall agriculture GDP is 21.83% in FY 2021-22 (BER, 2022). More than 12% population are directly or indirectly engaged in various activities of fisheries sector for their livelihood. Over the last four decades, the total fish production of Bangladesh has increased about six times (0.75 M t in 1983-84 to 4.62 M t in 2020-21) and the aquaculture production has increased by more than double from 1.06 M t in 2008-09 to 2.64 M t in 2022-21 exhibiting a consistent growth performance.

Aside from the climatic risks the country is facing challenges from the demand of increased food production, high yield gap, pollution at various extent, declining natural resources, inadequate input efficiency, low productivity, diversified food demand, farm labor shortage and high post-harvest loss , inappropriate market system and so on. Meanwhile, the government has adopted a good number of vision, policies, strategies and action plans for ensuring sustainable food and nutrition security.

Rationale

Transforming recent myriad necessities, future demand for increased food production and climatic problems towards prospects, the Government of Bangladesh is

committed to identifying and prioritizing investable sectors for actions to reduce climate risks and environmental losses in the vulnerable areas of the country. There is a dire need for sustainable agricultural production for feeding an increasing population of 184 million in 2030 and 197 million in 2040 (Fig. 2). Considering the per capita requirement, the country needs to produce a total of 102 M t food in 2030 and 109 M t in 2040 from agricultural sectors to feed the population in a given year as mentioned above. Bangladesh has produced a total of 89.4 M t food in 2021 (37.6 M t rice, 1.1 M t wheat, 0.43 M t pulse, 0.99 M t oilseeds, 3.60 M t spices, 14.5 M t vegetables including potato, 5.1 M t fruits, 4.5 M t fish, 11.9 M t milk, 8.4 M t meat and 23.35 billion eggs). Taking into account of 65 kg wastage of food by a Bangladeshi per year (UNEP, 2021), a total of 79 M t food became available from agricultural sectors for human consumption in 2021. If this 79 M t total food availability is considered business as usual from 2021, the country needs to increase its total production from agricultural sectors by 23 M t in 2030 and 30 M t in 2040. This means that the total food production needs to be increased by 29% in 2030 and 38% in 2040 if not otherwise constrained by severe impact of climate change.

Fig. 2. Population versus food production requirement of Bangladesh up to 2040 (Bokhtiar and Samsuzzaman, 2023).

Agricultural research in its present pace will no longer fulfil the above demand of the country well in the 21st century as arable land diminishes, population increases, and climate is changing. So, a new vision is needed in order to remake agricultural research, perhaps radically, to address the emerging challenges in the days to come. This entails devising Bangladesh Agricultural Research Vision accompanied by priority research as a dynamic document. There is a need to adjust the research priority with the contextual and temporal changes and to undertake demand-driven research to address the need of technology users. BARC being an apex body of the National Agricultural Research System (NARS), has the mandated functions to plan, execute, coordinate, monitor, and evaluate agricultural research in respect of national needs. The Council is assigned with a task of creating Vision Document and National Agricultural Research Plan at certain intervals commensurate with the national priorities and policies.

BARC as an apex body of the national agricultural research system has the responsibility of strengthening and coordinating the national agricultural research capability through planning and integration of resources. Its vision is to ensure competent, effective and sustainable agricultural research system whereas mission is to strengthen research skill in partnership with national agricultural research systems institutes, agricultural universities, private organizations and other associated organizations for developing modern varieties, appropriate technologies and innovative information toward agricultural development (www.barc.gov.bd).

More than a decade back, the BARC had published a vision document, Research Priorities in Bangladesh Agriculture: Vision 2030 and Beyond in 2011 which is still used for research planning and execution by the NARS and other research institutes. In course of time a number of transformation in the agricultural sector has been occurred and many policies and strategies like Vision 2041, Bangladesh Delta Plan 2100 etc. are adopted by the government. Emerging circumstances like youth's food habit, declining natural resource base, climate change, consumer's choices and market demand have taken new shapes. These novel circumstances are not possible to be addressed by the existing vision. Therefore, a new vision is required anticipating the future demand and scenario. Under these perspectives, a higher and sustained growth in agricultural production (crop, livestock and fisheries) is imperative for a rapid development of the economy and country's poverty reduction. In response to threats caused by various risks along with Covid-19, it is obvious to take some indispensable/obligatory initiatives and to redesign research vision as one of the preferred initiative meeting the current and future demand of food up to 2041. Thus, a current vision titled Bangladesh Agricultural Research Vision 2041 is inevitable with due attention to higher productivity and profitability through efficient natural resource management, adoption of good agricultural practices, crop diversification and intensification, mechanization, and market development. Consequently, undertaking appropriate research activities is a must to maintain a required growth trend that ensures a rapid rise in national income, achieving macroeconomic stability, product diversification and agro-processing, effective employment of growing labor force and, indeed, food and nutrition security, in respect of demographic change. It is important to note that the farm products exports is soaring to about 1.9 billion dollar in 2022, whereas imports budgeted to about to 10.84 billion dollar in 2021-2022 fiscal year (Bangladesh Bank, 2022). Recently BARC has estimated the demand and supply of major crops in order to recognize the problems and potentials in the subsector which is understood to be a great help for the policy makers in undertaking appropriate strategies and action plans to secure nutrition security toward a talent nation (Table 1) (Bokhtiar *et al.*, 2022).

Table 1: Projections of demand and supply of major crops (2021-2050)

Crop	2021		2030		2050	
	Million ton (M t)					
	Demand	Supply	Demand	Supply	Demand	Supply
Rice	35.20	35.66	39.10	41.04	42.60	52.13
Wheat	5.40	1.03	6.39	1.17	8.09	1.24
Maize	6.50	4.21	8.43	6.19	16.99	12.24
Potato	9.56	9.87	11.61	11.78	12.65	14.09
Pulses	1.61	0.39	1.79	0.55	1.95	1.02
*Edible oil	1.35	0.42	1.61	0.53	2.10	0.71
Vegetables	4.12	4.17	5.15	5.38	6.15	8.90
Fruits	2.67	2.94	3.22	3.55	4.37	5.16

Source: Bokhtiar *et. al.*, 2022 * Only mustard and groundnut are considered.

In formulating present research vision, both bottom-up and top down approach has been exercised to grasp information from all levels including grass root level workers giving due importance on real experiences of their locality. In the process, the various Agricultural Policies and Strategic documents (Crops, livestock and fisheries) were reviewed following synthesizing the recommendations stated in the documents and recognizing the issues for inclusion in the current vision document. The detailed procedure has been described in the methodology section.

Objectives

The main objective of the Agricultural Research Vision is to provide a general vision guide with key thematic issues and strategies as a direction for future researchers, policy makers and donors towards building a prosperous farm growth and sustaining productivity. Eventually the vision document will facilitate undertaking precise innovative research efforts for building a pulsating and prosperous agricultural production to meet the demand of increasing population until 2041. The general and specific objectives of the vision are outlined as follows:

General objective

Identify thematic research areas and strategic issues as guide for future researchers, policy makers, and donors towards building a vibrant and thriving agricultural production and income thet commensurate with the demand of population until 2041.

Specific objectives:

i. Facilitate undertaking research to achieve resilient competency in agricultural sub-sectors to tackle a wide variety of vulnerable conditions and swelling population.
ii. Expedite research focus ensuring sustainable, profitable and nutrition sensitive farming system under changing climate and increasing population.
iii. Help to accelerate deft agricultural diversification, intensification, mechanization, productivity enhancement and commercialization to warrant food and nutrition security, farm income and marketing system by adopting demand driven research endeavors and cutting edge technologies.

ACHIEVEMENTS IN BANGLADESH AGRICULTURE

In outlining a far-sighted vision of agricultural research, it is indispensable to review current scenario and consider the future situation of the sector so that it becomes a realistic and representative even under contextual changes and challenges ahead. In this perspective major thrusts, highlights of agricultural policies, transformation and achievements in crop, livestock and fisheries sub sectors are reviewed and endowed below.

Major Thrusts

The primary focus of the sector has been paid towards food sufficiency followed by nutrition and food safety, natural resource conservation and recently commercialization along with agro-processing, value addition and market development. In effect, the country has achieved self-sufficiency in rice since 2000 and became surplus from 2005 by 0.37 M t to 2021 by 7.55 M t (Fig. 3). The country has also attained surplus in fruit, meat and egg in 2010. Need, changing situation and consumers buying capacity and preferences have contributed to altering the thrust over times.

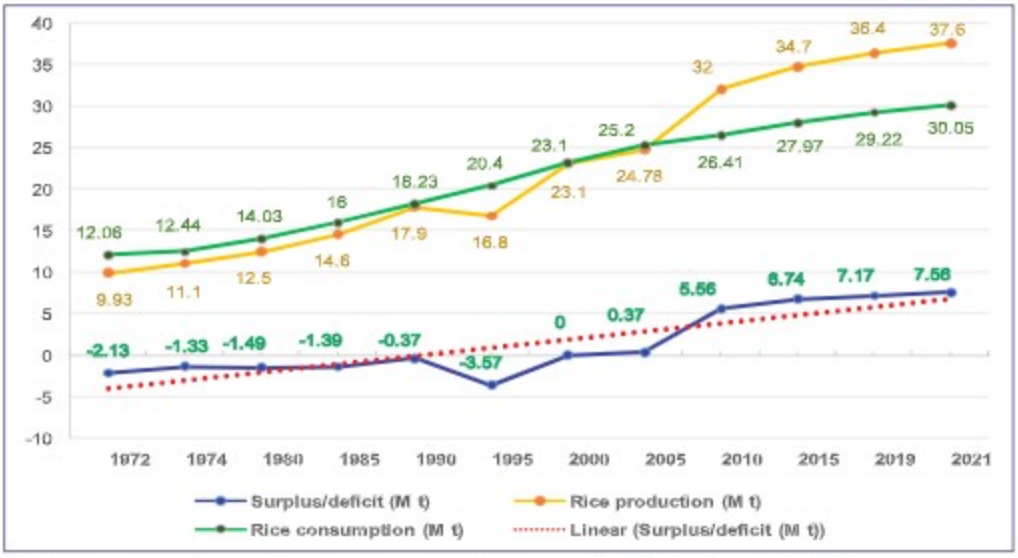

Fig. 3: Trend of rice production from deficit to surplus (Bokhtiar *et al.*, 2023)

However, an in depth wandering through visions and policies of the Government is inevitable to fetch flavor of the key thrusts. In both ministerial (Ministry of Agriculture, MoA and Ministry of Fisheries and Livestock, MoFL) documents some common issues like safe food, profitable and cost-effective higher production, agro-processing and sustainable natural resources management towards commercialization and productivity enhancement are heightened as major thrusts. Also, improvement of livelihoods

and creation of employment opportunities are emphasized. The Ministry of Agriculture (MoA) has drafted quite a significant number of policies and strategic documents compared to that of the ministry of livestock and fisheries in order to keep pace with the requirement of present and future era. Further, both the ministries have prepared a time-bound plan to promote export growth of farm produces. It is noteworthy that research issues are being embedded in most of the sub-sectoral documents without elaboration. However, the mission and vision along with objectives of the two concerned ministries involved in agricultural development is outlined below (www.moa.gov.bd, www.mofl.gov.bd) as an attempt to provide a glimpse on the key thrust.

The vision of the ministry of agriculture is sustainable, safe and profitable farming with mission to (i) ensure profitable agriculture and secure public nutrition and food security through increased crop production and productivity, (ii) nutrition rich safe crop raising and (iii) modernization of marketing system. It aimed to (i) increase availability of food, right to food and purchasing capacity by increasing productivity of crops and income; (ii) modernize agricultural research, education, extension, input management and develop skilled manpower for sustainable technology innovation; (iii) increase farmers' capability and income through institutional infrastructure development and efficient technology services; (iv) adopt and implement food production plans to meet the needs of nutritious, safe and demand-driven foods; (v) develop agricultural research for promoting export of products through coordination with local and international partner organizations; (vi) provide assistance to the farmers in increasing agricultural production and ensuring marketing facilities of agricultural commodities and obtaining fair prices; (vii) create sustainable agricultural production systems by increasing productivity through proper management of natural resources; (viii) reduce the use of physical labor and introduce cost saving farming systems through farm mechanization; (ix) create new sectors of agricultural commercialization and employment generation through demand-driven and export- oriented agricultural development and (x) ensure proper use of water resources through active participation after formulating strategies and their proper implementation through inter-ministerial/inter-agency and trans-boundary coordination.

The vision of the ministry of livestock and fisheries is safe and secure animal protein for all with mission to meet demand of animal protein by enhancing production, productivity and value addition of fish and livestock products. The aims and objectives of the ministry are to (i) increase fishery resources and production; (ii) increase livestock and poultry production and productivity; (iii) enhance export of fish, fishery resources and livestock products; (iv) maintain ecological balance, conserve bio-diversity and improve public health; (v) prevent and control diseases and (vi) generate employment towards poverty alleviation.

Highlights of Key Agricultural Policies

Agricultural policies are set of ideas or plans developed by the Government, which are used as the basis for achieving target of sectorial development according to demand and national vision. The Government of Bangladesh is working relentlessly for ensuring peoples' overall wellbeing through increased nutritious food availability, job creation and living standard. However, it is essential to review the current policies prior to setting country's research vision. Also, both UN and local relevant documents related to agricultural growth are consulted. It is beyond the scope of present endeavor in consulting all papers, instead, only a few key recent and extremely allied document has been consulted and organized as general and sector specific as below:

General documents

As an UN formulated document, Sustainable Development Goal (SDG) 2030 is the foremost one, as Bangladesh as a signatory country is committed to fulfill the targets adopted by the General Assembly of the United Nations as Agenda for Sustainable Development with the 17 goals in September 2015. The document shielded agricultural development under five goals, namely, Goal 2: Zero hunger - End hunger, achieve food security and improved nutrition and promote sustainable agriculture ; Goal 6: Clean Water and Sanitation-Ensure availability and sustainable management of water and sanitation for all; Goal 13: Climate Action: Take urgent action to combat climate change and its impacts; Goal 14: Life Below Water - Conserve and sustainably use the oceans, seas and marine resources for sustainable development; Goal 15: Life on Land - Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. It is an inclusive, pluralistic and enthusiastic document in perspective of all sub-sector of agriculture (livestock, fisheries and crops) and natural resources have been taken under consideration to be rationally addressed. The Goal 2 is specifically related to agricultural development through

i. doubling the agricultural productivity and incomes of small-scale food producers,

ii. ensuring sustainable food production systems and implement resilient agricultural practices – that increase productivity and production, help maintain ecosystems, strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and

iii. development of technologies and plant and livestock gene banks to enhance agricultural productive capacity in developing countries that increase productivity and production, progressively improve land and soil quality. (www.un.org /sustainable development)

The Bangladesh Delta Plan 2100 is a long term visionary text formulated in 2018 with a vision, Achieving safe, climate resilient prosperous delta (BPC, 2018). The research issues are embedded in the commitments like (i) ensure long term water and food security,

(ii) economic growth and environmental sustainability, while reducing vulnerability to natural disasters and building resilience to climate change and other delta change through robust, adaptive and integrated strategies and equitable water governance; (iii) food security, environmental sustainability, building climate change resilience through a holistic approach. The Bangladesh Delta Plan 2100 is such a far-sighted policy document wherein the present and future climate and natural disaster driven challenges has been considered to be addressed though technological interventions and adoption with equitable use of water resources.

The vision of Bangladesh Perspective Plan: 2021-2041 is towards a high-income economy: paradigm shifts in agriculture will enhance productivity and ensure nutrition and food security for the future and building a Bangladesh resilient to climate change and other environmental challenges (BPC, 2020a). The document has emphasized farm sector with research issues like ensuring food security, and nutrition bound research on (i) bringing unfavorable agri-ecosystems under productive sustainable agricultural practices; (ii) intensifying crop cultivation in productive agricultural land maintaining soil health; (iii) intensifying agricultural production systems in the limited agricultural lands; (iv) increasing resilience of crop and livestock production systems under climate change vulnerabilities; (v) diversification in agricultural output and livelihoods involving more plant species or varieties, or animal breeds, off-farm activities and employment; and (vi) coping with uncertainty in developing responses needed to address climate vulnerability.

The Eighth Five Year Plan: 2021-2025 set its vision as Promoting Prosperity and Fostering Inclusiveness highlighting focus on research areas with specific targets (BPC, 2020b). These are (i) developing and refining technologies to bridge up yield gaps and promote diversification and intensification; (ii) sustainable natural resources management; (iii) disease and pest management; (iv) Development of varieties/species with postharvest technology of high value agricultural commodities; (v) frontier research like genomics and phenomics, physiological mechanisms regulating photosynthetic efficiency, poly shed and nutrient dense culture, vertical farming, mechanization, etc. (vi) mitigation of climate change effects by breeding and introducing stress tolerant, short duration varieties, high value commodities, and low-cost, high-impact postharvest technologies; (vii) research on packaging, harvesting, food processing, market intelligence, IPM, on-farm water management, food technology and (viii) emphasize biotechnology and biosecurity along with other contemporary issues.

The Third Country Investment Plan: 2021-25 has envisioned towards national sustainable development through the enhanced provision of ecosystem services, thereby helping to reduce poverty, improve environmental and human health benefits, and increase resilience to climate change. This plan has research scopes for (i) improved technology for more productive nutrient-rich and sustainable agriculture; (ii) climate smart technologies for reducing production losses; (iii) facilitate production in coastal and newly developed lands including hydroponics in saline land; (iv) improved technologies of micro nutrient dense fruits and vegetables; (v) improved breeds of livestock, poultry and fish with high

quality protein and bio-available micronutrients; (vi) bio-fortification in crops (vii) efficient and environmentally friendly irrigation technology; (viii) develop blue economy; (ix) improvements in postharvest management and marketing, (x) inclusive cooperative/ group-based processing and marketing; (xi) increased resilience of agriculture systems; (xii) innovations to incentivize production in urban and peri-urban areas: rooftop gardening, vertical farming, hydroponics; (xiii) novel approaches for water efficient technology dissemination; (xiv) develop new sustainable and energy efficient irrigation technologies in collaboration; (xv) access to clean and sustainable technologies with the promotion of solar powered irrigation; (xvi) accelerated use of cost-saving fertilizer; (xvii) quality seed production and (xviii) production of quality feed and fodder. (BPC, 2020c).

Sectoral documents

Crops sub-sector

This sector is led by the ministry of agriculture and has prepared a good number of policy documents aligning SDGs, Vision 2041, Bangladesh Delta Plan and national targets as outlined below:

National Agriculture Policy 2018 (www.moa.gov.bd)

The National Agriculture Policy 2018 is one of the most relevant document wherein research issues have been signposted in much detail with vision of achieving sustainable, safe and profitable farming bearing a separate part on research. The research targets include:

i. undertaking modern research to increase the productivity and production of crops through innovating appropriate technology

ii. development of climate resilient, adaptive, eco-friendly, post-harvest loss minimization, agro-processing, input efficiency, conservation and utilization of natural resources, and increasing quality seed supply

iii. research on cutting-edge technology development like biotechnology and nano-technology, farm mechanization, socio-economic aspects

iv. research for inventing nutrition-rich pulse, oilseed and other cash crops and

v. genetic resources, microbiological research, non-conventional and non-seasonal crops, pest management, farming systems research, crop diversification, increase of cropping intensity and minimization of yield difference and invention of modern dissemination system research .

Climate Resilient, Early and Short Duration Crop Variety and Technology Development Policy 2010 (www.moa.gov.bd)

The document is very specific towards variety and technology development with set aims and objectives to develop

i. salinity, drought and heat tolerant high yielding varieties;
ii. flash flood, water-logging and submergence tolerant high yielding varieties;

iii. short duration high yielding varieties;
iv. water use efficient high yielding varieties;
v. low input responsive/nutrient efficient high yielding varieties;
vi. development of appropriate cultivation and management system and
vii. development of farming systems for newly accredited char land.

Fisheries sub-sector

National Fisheries Policy 1998 (www.mofl.gov.bd)

This policy set its vision to 'Enhance fish production and increase foreign currency earnings for economic growth, ecological balance and biodiversity conservation'. It has quite a number of research targets like

i. maintains ecological balance, conserve biodiversity, ensure public health and provide recreational facilities;

ii. emphasizes aquaculture through adoption of appropriate technology in the open water bodies;

iii. shrimp and fish culture in coastal areas in a sustainable manner to conserve biodiversity and reduced environmental damage;

iv. appropriate studies on exotic fish before introduction and promotion;

v. spawning of freshwater giant prawn and production of post-larvae in all public hatcheries after feasibility studies;

vi. ensures quality to exportable fish and shrimps;

vii. develops aquaculture packages in developing private entrepreneurs;

viii. improves production and exploitation of 'Hilsa' through identification and conservation of their breeding grounds and removal of any obstructions;

ix. undertakes sustainable exploitation and management by the estimation of marine fisheries resource survey;

x. develops capacity for using modern fish harvest techniques and

xi. improves traditional fish processing technologies and value addition.

National Shrimp Policy 2014 (www.mofl.gov.bd)

The vision of the policy is to maintain environmental and ecological balance, protecting biodiversity and job creation as well as shrimp production, processing, marketing and export market expansion. Research related context of the document includes many issues like

i. invention of desired technologies and application to desired volume of shrimp production through due plans keeping pace with target region's specificity;

ii. introduces sustainable conservation, management and harvesting strategy in shrimp grown naturally in the sea and open water;

iii. regulating rational harvesting of brood shrimp;

iv. emphasizes integrated eco-friendly shrimp cultivation, diversification and rotation;

v. introduces scientific methods for conserving shrimp quality, production, harvesting, transport, processing, marketing etc. as per consumers' demand through value addition, marketing and export for high earnings and economic growth;

vi. undertakes actions for keeping environmental balance, biodiversity conservation and public health improvement of shrimp growing locality and

vii. commensurate shrimp related education, training, promotion and research.

Livestock sub-sector

National Poultry Development Policy 2008 (www.mofl.gov.bd)

It entails vision as encourage poultry industry and to control quality of inputs for sustainable poultry development, highlighting research and extension on

i. development of locally adaptive modern poultry breeds;

ii. management of poultry waste;

iii. modernization of poultry extension and health services;

iv. conservation of genetic potentiality of local poultry to develop high yielding climate resilient local breed;

v. development of sustainable technology suitable for poultry rearing in rural areas;

vi. development of wet market biosecurity, poultry marketing, conservation and waste management system;

vii. strengthening poultry disease surveillance and

viii. encouragement of year-round family and commercial poultry rearing.

Transformation in Agriculture

Bangladesh agriculture enjoyed a chronological transformation towards paradigm development. This transformation started with power pump irrigation using surface sources of water for boro rice (winter) cultivation and gradually shifted to use of groundwater with deep and shallow tube wells and covered crops grown in other seasons. It accompanied pesticide and fertilizer use to boost up production facilitating

the Green Revolution from early 1970s to early 1990s. Agricultural production, especially rice and wheat, increased significantly due to green revolution. However, irrational use of pesticide and fertilizer caused damages to the environment, specifically brought huge bio-diversity loss and pollution. However, key changes are noted under each sub-sector.

Crops

Meeting increased food requirement with fading natural resources in context of demand for high value and nutritious crops under global warming is a huge challenge. The country's adopted strategies are helpful in transforming the sector through increased food availability, right to food and purchasing power aided by higher productivity and production and increasing farmers' capability and income. These strategies also contributed to institutional infrastructure development, efficient technology innovations and adoption and implementation of food production plans. One of the key transformations, which gains momentum, is the significant increase of maize production in the country. Maize has occupied large areas with 5.63 M t production during 2021-2022 (www.moa.gov.bd) and has been used as food, feed, and raw materials of other industries. As a result of fast transformation the country ranks first in exporting jute and is one of the top producers of jute and jackfruit (second), rice (third), vegetables and onion (third), mango and tropical fruits (sixth), potatoes (seventh) and guava (eighth) (www.moa.gov.bd). Such a fast transforming agriculture is now visualized due to social and economic development followed by a strong political will having implications on resource use, food production and technology development.

During last three decades, the self-reliant perspective in rice has dominated the food production and agriculture policy agenda. Since 2007, the government has been supporting the sector by assisting farmers with enhanced input supply at subsidized rate, production incentives, increased credit facilities, farm mechanization, price support through public procurement, policy interventions etc. Farm mechanization is one of the priority areas of the Government for cost effective production and mitigation of the labor crisis arisen due to their migration to non-farm sectors. Some of the major transformations that have happened in country's agriculture sector are narrated below:

The average land holding per household is decreasing, which has limited the scope for accelerating farm mechanization. The number of small and landless farmers is increasing. Although the share has declined, rice still covers over 70% of the grown cropped area. The adoption of HYV rice increased significantly in the Aus and Aman season in the last 25 years. Yet, traditional low yielding varieties still covers 30% of Aman's rice area. The adoption of HYV and improved management practices increased rice yield significantly. Crop diversification, which has been low, is gradually increasing. Non-rice crop share increased from 25% in 1988 to 29% in 2013. The cropped area of maize, wheat, fruits and vegetables is expanding. A comparative crop production and growth of major crops has been furnished in Table 2 demonstrating the sectoral achievements.

Table 2: Comparative crop production and growth in Bangladesh (BBS, 2009; BBS, 2022; www.moa.gov.bd)

Crop	Production (million tons, M t)		Growth (%)
	2008-2009	2021-2022	
1. Rice	31.32	39.18	25
2. Wheat	0.85	1.09	28
3. Maize	0.73	5.63	671
4. Cereal crops (rice, wheat, maize)	32.90	45.90	40
5. Potatoes	5.27	10.15	93
6. Pulses	0.20	0.84	320
7. Oilseeds	0.66	1.23	86
8. Vegetables	7.37	21.67	194
9. Fruits	3.17	5.34	68

Bangladesh ranks first and third, respectively, in respect of area under vegetable cultivation and production growth. As of today, Bangladesh Agricultural Research Institute has released 134 vegetable varieties so far (107 open pollinated, 23 hybrids and four transgenic eggplant). Besides, Bangladesh Institute of Nuclear Agriculture, other government, non-government organizations and universities have contributed significantly to innovating vegetable varieties. Bangladesh Agricultural Research Institute (BARI) has developed 98 fruit varieties which accelerated increase in fruit production. It has brought Bangladesh into the list of top ten countries producing seasonal fruits. Mango and jackfruit were the only major fruits produced among 56 types in the country 20 years ago whereas at least 72 types of fruit are being farmed presently. People are consuming more fruit than before as manifested with increased per capita per day fruit consumption of 85 grams in 2018 against 55 grams in 2006. Fruit production rose by 68% during the last 12 years. Besides local fruits, Bangladesh has been farming some exotic fruits like dragon, malta, oranges etc. Cashew nut and coffee beans are now in cultivation in the hilly areas of the country (Financial Express, 2022).

Consequently, Bangladesh has earned US $164 M from exporting fresh vegetables (Islam, 2022). The country also earned foreign currencies from exporting ago-products like edible vegetables and certain root and tubers (US $99.91 M), coffee, tea, meat and spices (US $49.54 M), ginger, saffron, turmeric and other spices (US $39.66 M), sugar confectionery (US $26.93 M), malt extract, food preparations of flour (US $67.23 M), and fruit and vegetable juices (US $58.20 M) in last year. Export of agricultural products from

Bangladesh fetched over US $1billion in FY2022. Besides, export earnings from tobacco and tobacco products with US $107.22 million in the last fiscal year also have shown upward trends. In total 35 kinds of fruits, vegetables and spices are exported to a number of countries, mainly for ethnic people of Bangladesh residing in the Middle East as work immigrant (EPB, 2022).

During the last era, 656 improved crop varieties including stress tolerance have been evolved by National Agricultural Research Systems (NARS) Institutes. Among these, 287, 58, 14, 8, 7 and 71 varieties have been developed, respectively, by BARI, BRRI, BJRI, BSCRI, CDB and BINA. Among the stress mitigating rice varieties, there are 13 saline tolerant, six sub-mergence tolerant, 10 drought tolerant, six zinc rich, three low glycemic index, three suiting tidal flood and 11 targeting haor areas. In addition, four transgenic eggplant varieties are being evolved to address threat of fruit and shoot borer and safeguard environment and ensure safe vegetables production. The government has been continuing development assistance in fertilizers, electricity for irrigation and sugarcane production through subsidy to keep cost effective farming in place. During 2009-2010 through 2020-2021, the amount of subsidy to fertilizer, electricity for irrigation and sugarcane was about Tk. 82,866 crores. Seventy-one thousand and two hundred forty farm machineries including combined harvester, reaper, seeder, power tiller at 50-70% subsidy are distributed among farmers as development assistance to accelerate mechanization during the period. Consequently, farm labor crisis has been addressed and cost effective production has been ensured saving crop through quick harvest before flash flood despite COVID-19 pandemic situation. Adequate marketing of farmers' produces has been ensured by establishing 18 assemble centers, 82 growers' market, 12 processing centers and regional training centers. In 2018-19, Tk. 4.33 crores loan has been disbursed among farmers against deposit of crops totaling 4,286 tons under Crop Godown Loan Program. Under supervision of the Ministry of Agriculture, Farmers Market has been in operation to hoard pesticide free vegetables. Presently in 41 districts such markets are established, and famers are benefitting from getting fair price of their produces though this exertion.

However, in crop sub-sector, development of day neutral vegetable varieties and short duration and lean season fruit varieties have contributed to their year round availability. Moreover, expansion of potato acreage, increased availability of quality seeds and planting materials, introduction of exotic vegetable varieties, adoption of IPM technologies towards reduced pesticides use, increasing mechanization trend and escalated initiatives of private sector are very evident in transforming country's farm sector.

Due to fragmentation of holdings arisen out of inheritance pattern and population increase, the sector becomes unable to support livelihoods of entire population and to employ labors for full time. Also, farm machineries are increasing over days to foster cost effective farming and save turn-around time offering opportunities to accommodate more crops in the same land for enhancing food and nutrition security. All these factors led labor migration from farm to non-farm sectors wherein full time employment is available with high wages. However, growth opportunities remain in

high return bound agro-enterprises, value addition in farm produces and popularization of value added products through appropriate marketing linkages.

Livestock

Livestock are the chief sources of quality animal protein extremely essential to support a healthy and commendable nation. The sector is committed to meet the demand of animal protein by enhancing production, productivity and value addition towards safe and secure animal protein for all. About 20% population are directly involved and 50% of them are indirectly engaged for their livelihood. Livestock production in the country is transforming from traditional farm animal production into inputs supported commercial production system to fulfill the nutritional demand of vast population by 2041. The services of the sector have stretched up to farmers' doorstep to guarantee technical support for safe production of livestock and poultry. During the last decade, the key performance indicators demonstrated that production of meat, milk and egg has been increased by many folds and some key initiatives and achievements are furnished below (www.mofl.gov.bd).

The sectoral contribution to national GDP and contribution of livestock growth to national GDP and agricultural GDP are estimated to be 1.74, 3.80 and 13.10%, respectively. A long term initiative has been undertaken to ensure sustainable milk production through improvement of livestock breed, milk and milk product markets management systems, quality regulation and easier availability and habituating milk drinks. As a consequence, per head per day milk availability has reached to 208 against 250 ml of daily requirement. The total production of milk has increased to four folds as in 2020-2021 compared to 2010-2011.

Incessant investment and commercialization have become a reality in the sector in perspective of Government policy support. Consequently compared to 2010-2011, the meat production has risen by 4.25 times to about 8.44 M t with 147.8 g/head/day availability against requirement of 120 g/head/day. Following investment in layer bird development, Grand Parent Stock and establishment of Grand Parent Stock Farm, expansion of commercial farms and quality poultry feed production has led achieve a high growth in egg production. A revolution is noticed in egg production that there was 2057.64 crores eggs in 2020-21 compared to 607.85 crores eggs in 2010-11 with a 3.4 fold increase, that has led to an availability by 136 against 104 per head per year requirement. During the last decade, a consistent growth in the livestock products transformed the country into self-sufficiency in meat and egg production with an ample scope for export opportunity. In last four years, the animal demand to sacrifice during the Eid festival has been satisfied with local livestock, even 2.8 M animals were in excess than requirement with Tk. 46430.05 crores transactions and its lion share has been transferred to the marginal people from rich that has contributed a lot in pulsating rural economy (www.dls.gov.bd)

The livestock semen production was 2.584 M doses in 2010-2011 but it has been uplifted to 4.441 M doses as an effort to breed development and artificial insemination. During the period 4.365 M heifer have been artificially inseminated country wide through

establishing 4,694 artificial insemination sub-center/point. Nine 'Proven Bull' has been developed scientifically to increase livestock productivity and to use for artificial insemination, accordingly, more milk and meat producing cows are increased. Twenty four quarantine stations have been set up in airport, land and seaports to face threats of trans-boundary diseases spread. An accredited and ISO certificate awarded country's first quality lab has been established to support livestock products' quality control and export.

Unemployed 9.2 million youths, young and distressed lady, landless and marginal farmers have been trained during the last decade on livestock and poultry rearing to be self-employed. As a part of digitalization the Department of Livestock Services has been rendering services to farmers on livestock rearing, diagnosis and treatment and related problems through 16358 toll free number by SMS.

Bangladesh Livestock Research Institute (BLRI) so far has developed 91 technologies in livestock and poultry production, health, feed and nutrition and management issues. Among these, beef fattening, development of cattle breed, BCB-1, Layer Strain-1 and 2, *in vitro* embryo production technology, vaccines against PPR, Goat pox, *Salmonella*, Gumboro and LSD, strategic control model for anthrax, BQ, FMD, and PPR, Mina mix, Milk replacer, calcium fatty acid salt, corn-straw pellet feed, complete feed pellet, starter feed are notable inventions which are playing important role in boosting growth in livestock sector. Besides, the institute is conserving and improving 53 different types of indigenous and exotic animal breeds as well as establishing a Fodder Germplasm Bank, conserving 54 local and exotic fodder varieties (www.blri.gov.bd).

Fisheries

The Bangladeshi people gets 60% of their animal-protein needs from fish. The country found 1.25 million tons of capture fish production in 2020, which was 11% of the total global figure, compared to 16% by India and 13% by China. Due to various public policies, strategies and fishery-friendly activities, a good number of transformations are being held in the sector. Key transformation taken place in the sector (SOFIA, 2022) are enumerated below.

The sub-sector is currently making an important contribution in meeting the food needs of the growing population of the country in terms of creating employment opportunities, alleviating poverty and earning foreign exchange. In the last 10 years, Bangladesh stood second in terms of average growth rate of fish production. It has positioned the country with 4th in Tilapia production in the world and 3rd in Asia. It is 1st in 'Hilsa' production and as a single species has been making the highest contribution (12.23%) in the country's total fish production. In 2021-22, fisheries sector contributes 2.08% to the national GDP and 18.09% to the agricultural GDP (BER, 2022). More than 12% of populations are directly or indirectly engaged in various activities under the sub-sector for their livelihood. Over the last three decades, the total fish production of Bangladesh has been increased by more than six times (0.7 M t in 1983-84 to 4.62 M t in 2020-21) showing a consistent growth performance.

Inland aquaculture of indigenous and exotic carp species as well as pangas, tilapia and koi has been expanded dramatically and farming of valuable, nutrient-rich indigenous species like *koi, shing, magur, pabda, gulsha, mola*, etc. draw special attention among the farmers. In addition, new farming technology like pen culture, cage culture, new species, and intensification of pond farming in particular helped the country to experience fast growth in aquaculture. The rapid development of shrimp and fish hatchery and nursery mostly owned by the private entrepreneurs has helped promotion and quick expansion of aquaculture during the recent decades. But there is some seed quality problem as well as crap seed quality deterioration including inbreeding, negative selection, non-availability of quality brood and improper brood management practices, non-availability of virus free mother shrimp and overall non-compliances in hatchery operation protocol. Several special programs like establishment of fish hatchery regulations, monitoring and capacity building of the government and private hatchery operations etc. are being undertaken to address the problems. Eventually fish production has become more than double in the last 16 years. Such great contribution is achieved due to adoption of improved farming practices by the farmers supported with required extension services.

Bangladesh's agriculture is experiencing rapid transformation despite declining farm size and increased tenant farming. With regard to social policies, there has been a notable evolution over the years, such as the transformation from relief to development programmers and the conversion of universal price subsidies to targeted food distribution and conditional cash transfers. Although low in the global context but yield and production of crops, fisheries and livestock are increasing over times. On the other hand, diversified rural economy and increased dependence on rural non-farm sector for livelihoods become tangible. Along with expansion of rural non-farm economy, part time farming has been expanded. Increased production and import of agricultural commodities accompanied by targeted distribution of food under social safety net programs increased per capita availability and consumption of food items by both poor and non-poor households.

AGRICULTURAL RESEARCH IN BANGLADESH

A good number of government, non-government organizations (NGOs), universities, private companies and international organizations have been contributing to developing high yielding varieties/breeds and improved management practices through Research and Development (R&D) for agricultural development. The lion share of the contribution is from 13 public agricultural research institutes of National Agricultural Research System (NARS). The main objective of the system is to contribute towards development of a pluralistic agricultural research. The specific objectives are to—

a. create highly effective and coordinated research organizations, devoting special attention to commodity and farming systems research, and meeting the needs for training to agricultural and development agencies;
b. transform agricultural production into a modern science-based market-oriented agriculture capable of greater efficiency, profitability and sustainability that will ultimately contribute to food self- sufficiency and poverty eradication;
c. promote agricultural industries through R&D for the purpose of contributing to the improvement of the quality of life and livelihoods of the people, protecting the environment; and
d. support the development and implementation of national policy with relevant information and knowledge.

Under the provision of Bangladesh Agricultural Research Council Act 2012, National Agricultural Research System (NARS) has been formed with BARC as the apex body and 13 public agricultural research organizations are the constituent units.

Research at NARS

NARS consisting of thirteen public research institutes, which belong to five ministries, is operational in Bangladesh. BARC as the apex body of NARS is mandated to coordinate agricultural research and development in the country through capacity building and research prioritization. Major role of NARS institutes are highlighted below.

BARC is mainly mandated to coordinate, monitor and evaluate the research programs of the NARS institutes and other associate organizations. It formulates national agricultural research plans and oversees their implementation. It takes care of human resource development (HRD) through arranging training and higher studies of agricultural scientists.

Under the supervision of Ministry of Agriculture, BARC coordinated with NARS institutes and contributed to the formulation of National Agriculture Policy 2018, an action plan for achieving SDG Goal-2, 8th Five Year Plan (2020-2025) and Vision Document 2021 and Agriculture Research Vision Document 2030. It also prepared Fertilizer Recommendation Guide (FRG)-2018 in continuation of FRG-2012 for optimum and region-specific use of fertilizer for the maximum production. BARC has

developed farm mechanization road map 2021, 2031 and 2041 to encounter the problem of labor shortage in agricultural production and to minimize postharvest losses.

BARC recommended to National Seed Board for release of more than 170 varieties of different notified crops. It also facilitated development of more than 50 promising technologies on crops, livestock and fisheries through implementation of Sponsored Public Goods Research (SPGR) sub-projects under NATP Phase-I and similarly 116 technologies so far through Competitive Research Grant (CRG) and Programme Based Research Grant (PBRG) under NATP-2. It also acts as a bridge to disseminate the technology transfer from research organizations to the extension agencies. BARC has prepared crop zoning maps for 17 crops for optimum utilization of land, soil and other natural resources with a view to maximize crop productivity.

Bangladesh Agricultural Research Institute (BARI) conducts research on all crops except rice, sugarcane, jute and tea. It has successfully contributed to national agricultural production by developing a total of 1,166 technologies of which 590 are crop varieties and 576 are related to crop management, agricultural machinery and equipment, post-harvest technology, farming systems technologies from 1972 to 2020 (Bokhtiar *et al.*, 2021). BARI developed heat tolerant wheat and tomato varieties (www.bari.gov.bd).

Bangladesh Rice Research Institute (BRRI) carries out research on all aspects of rice, including breeding of new varieties, improvement of yields, plant protection measures, fertilizer management and cultivation practices, and rice-based farming practices. The institute has made a significant contribution to the self-sufficiency of rice production in the country by developing 103 high yielding varieties and 8 hybrids. These varieties include salt, drought, cold and submergence tolerant along with zinc, iron, antioxidant-enriched and diabetic-patient friendly rice. Innovation of short duration variety like BRRI dhan33 was successfully cultivated to avert so called 'monga' (seasonal food deficit) situation in the northern Bangladesh. During the last 52 years, rice production increased by three folds, matching with the increase in population that was almost doubled. Nineteen BRRI developed rice varieties are cultivated in 14 countries around the world. BRRI has also developed 51 profitable rice-based cropping patterns for different Agro-ecological Zones (AEZ) and 32 improved agricultural machineries. Moreover, it has developed producer and consumer preference model for BRRI varieties. It has preserved about 8,000 rice germplasm in the BRRI gene bank collected from home and abroad (www.brri.gov.bd).

Bangladesh Jute Research Institute (BJRI) conducts research to develop short duration high yielding varieties of Jute, kenaf and mesta, and develop crop production and crop protection technologies. It also conducts research on jute industry for the development of value-added and diversified jute products and improvement of traditional jute products, and development of jute-based textile product in combination of jute, cotton, and other natural and artificial fibers. A total of 50 varieties of jute, mesta and kenaf, 75 agriculture technologies and 40 industrial technologies were so far developed by BJRI. Among these, BJRI Tosha pat-8, salt-tolerant BJRI Deshi pat-8 and Auto-Jute Power Ribboner are promising technologies for jute production. In addition, natural additive

treated jute geotextile, low-cost easy preparation of charcoal from jute stick, low cost light weight jute shopping bag, fire proof jute fabric, jute-plastic composite, jute wool and wool made sweater, and blanket from jute, cotton and sheep wool etc. are notable technologies for value addition. Genome sequence of tossa jute, white jute and a most devastating fungal pathogen *Macrophomina phaseolina*, the causal organism of stem rot of jute, was unveiled. BJRI has a gene bank, which conserves about 6,000 germplasms of jute and fiber related crops (www.bjri.gov.bd).

Bangladesh Sugarcrop Research Institute (BSRI) conducts research on the development of high yielding varieties, production technologies and multipurpose uses of sugarcrops. Based on sugarcane, major sweetener sources i.e. sugar and gur (jaggery) industries are developed in the country. Along with sugarcane, BSRI is presently conducting research on other sweetener crops such as sugarbeet, palmyra palm, date palm, stevia, *golpata,* and honey bee and liquor ice as well. Since its establishment, it has developed and released 44 varieties of sugarcane including 2 chewing type varieties. It has registered two varieties of sugarbeet, one year-round palmyra palm and one stevia. Moreover, it has developed 221 technologies on sugarcrop production, gur processing, preservation and marketing (www.bsri.gov.bd).

Bangladesh Institute of Nuclear Agriculture (BINA) has developed many varieties of different crops using the radiation technology. The institute conducts research to develop biological nitrogen fixation inoculum for different pulse and oil seed crops, along with non-commodity technologies. BINA so far has succeeded in developing and releasing 103 high yielding varieties of 18 important crops and 28 management technologies by using nuclear techniques. Among these, short duration, submergence and drought tolerant and aromatic varieties of rice, drought tolerant sesame varieties etc. are notable. Innovation of short duration variety like Binadhan-7 was successfully cultivated to avert so called monga situation in the northern Bangladesh (www.bina.gov.bd).

Soil Resource Development Institute (SRDI) is responsible for identification of soil characteristics, their classification, and property elements for suitability of crop production. In Addition to soil testing laboratories in different places, SRDI has mobile units to carry out soil testing at the field level. The institute has 10 Mobile Soil Testing Laboratories (MSTL), which provide on-farm soil testing facilities including fertilizer recommendations to the farmers. Some innovative technologies for slopping hill soil and saline soil management were generated (www.srdi.gov.bd).

Cotton Development Board (CDB) is responsible for increasing cotton production and conducting research on different aspects of cotton. CDB has been developing hybrid and short duration high yielding cotton varieties with desirable fiber characteristics. It has also been generating agronomic management technologies to increase productivity, improving soil fertility by integrated management of organic and inorganic fertilizers and developing bio-pesticide in controlling cotton insect pest and cotton disease management. It has developed 52 technologies of which 16 upland and 3 hill cotton varieties, and 33 crop management technologies for hybrid and modern cotton (www.cdb.gov.bd).

Bangladesh Wheat and Maize Research Institute (BWMRI) conducts basic and applied research to develop climate-smart variety and crop management technologies. It has developed 5 high yielding, heat tolerant and disease-resistant wheat varieties and 2 hybrid maize varieties (www.bwmri.gov.bd).

Bangladesh Forest Research Institute (BFRI) conducts research on scientific and efficient utilization of forest products and for increasing the productivity of forest land. It has developed improved technologies for increasing forest productivity, conservation of soil and water, protection of trees from pests and diseases using conventional breeding, biotechnology and genetic engineering, etc. BFRI is pioneer for artificial regeneration of mangrove species and raising man-made mangrove plantations. The institute has developed various seedlings nursery and established new garden system in coastal region, which has provided positive impact on development of mangrove forest in coastal region. BFRI has developed tissue culture protocol for 13 bamboos, 7 medicinal and 6 tree species. It has conserved 33 species of bamboo and 221 medicinal species (www.bfri.gov.bd).

Bangladesh Tea Research Institute (BTRI) conducts research to increase yield and improve the quality of tea by developing high yielding tea clones, packaging management technologies and rendering advisory services to the tea industry to transfer proven and adaptive technologies. BTRI has developed 20 clones, four hybrid bi-clonal and one polyclonal seed stock with high yield and quality. It has conserved 519 germplasms in its gene bank. BTRI has also developed and patented a soft drink "Cha-Cola" from tea. Different Green tea, value-added tea like White tea, Masala tea, Satkora tea, Zinger tea, Tulsi tea, Zira tea and Earl Grey tea were manufactured (www.btri.gov.bd).

Bangladesh Sericulture Research and Training Institute (BSRTI) is mandated to work on development and transfer of appropriate technologies for sericulture. It is also responsible for providing technical support and generating skilled manpower through training for development and extension of sericulture in the country. BSRTI conducts research on collection and conservation of germplasm materials both for mulberry and silkworm. More than 100 sericulture technologies were developed by BSRTI. It has conserved a total of 82 mulberry germplasms and 112 silkworm races in the Germplasm Bank (www.bsrti.gov.bd).

Bangladesh Livestock Research Institute (BLRI) has been carrying out adaptive research on field problems relating to livestock and poultry development. It has developed 71 technologies including five breeds (two livestock and three poultry), one fodder variety and 65 management technologies (53 on livestock and 12 on poultry Production). The institute also has conserved 24 different types of farm animals and poultry species, and 43 different varieties of fodder crops of native and exotic origins. Among the above technologies, some notable ones are (i) layer strains Shuvra and Swarna, (ii) Avian Influenza H5NI antigen, (iii) preservation technique of green forage by dole method, (iv) FMD control model, (v) TMR technology, (vi) Buffalo fattening technology, (vii) commercial model of Bangla lamb production from local sheep, (viii) sheep rearing techniques in hilly areas, (ix) bio-security model for commercial poultry farm, (x) urea

molasses straw (UMS), (xi) fresh and wet preservation of straw, (xii) green grass preservation and (xiii) maize stover preservation (www.blri.gov.bd).

Bangladesh Fisheries Research Institute (BFRI) aims to generate various aquaculture breeding and management technologies for sustainable increase in fish production without undermining natural resource base. The institute has devolved 61 new technologies of which nine on fish breeding and seed production, 35 on fish culture, seven on integrated farming, three on management and policy formulation and seven on biotechnology. Out of these technologies, seven are widely disseminated. Remarkable research achievement has been obtained in breeding and culture of local endangered fish species, riverine cat fish, prawn and shrimp culture, and hilsa fishery management. BFRI has also been able to conserve about 23 endangered species of native fish (www.bfri.gov.bd).

Research at University

Several universities viz. Bangladesh Agricultural University (BAU), Sher-e-Bangla Agricultural University (SAU), Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Sylhet Agricultural University (SAU), Chattogram Veterinary and Animal Sciences University (CVASU), Hajee Danesh Science and Technology University (HSTU), Patuakhali Science and Technology University (PSTU), etc. conduct education, research and training on agriculture related to production of crop, livestock, fisheries and forestry.

Bangladesh Agricultural University (BAU) through its Fruit Tree Improvement Project (FTIP) has developed 108 high yielding varieties out of which 83 on different fruits (25 mango, 10 guava, 04 jujube, 04 lemon, 05 jambura, 03 kamranga, 03 jamrul, 02 malta, 04 safeda, 04 dragon fruit, 04 litchi, 02 banana and other 13) and 25 on different crops (01 rice, 05 garlic, 03 carrot, 04 sweet potato, 07 potato and 05 yam).

Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU) has so far developed 51 high yielding varieties of different crops viz. vegetables (30), fruit (05), pulse (06), oilseeds (03), spices (02), flower (02) and rice (03).

Sher-e-Bangla Agricultural University (SAU) is established with a view to imparting higher agricultural education and simultaneously to conduct time demanding research activities to generate new technologies on agriculture. Many research projects were undertaken by the different departments of the university. Through collaboration among teachers, researchers and students, SAU Central Research System (SAURS) has developed SAU Sarisha-1, SAU Sarisha-2 and SAU Radish. It also conducts research on various rose of red, pink, purple, black and green colour. Red Baby, Sweet Love, Pink Smile, Charming Lady, Mini- Moni, Lemon Star, Dream Bangla, Pain Blue, Bijoy-71, SAU- King are the 10 invented varieties of rose.

Sylhet Agricultural University (SAU) has developed several new technologies, new breeds of livestock and hybrid varieties of crops. SAU has so far developed 45 technologies of which two on HYV vegetable, 15 on crop science, 6 on veterinary science, 6 on fisheries science, two on biotechnology and 14 on farm power machinery.

Chattogram Veterinary and Animal Sciences University (CVASU) has developed a total of 13 technologies of which 03 on poultry, 03 on livestock, 04 on fishery management and 03 on other areas. A new breed crossed between Faomi and indigenous chicken has been developed, which can grow rapidly as Faomi but the taste of its meat is the same as that of the indigenous chicken.

Hajee Mohammad Danesh Science and Technology University (HSTU) conducts applied research studies leading towards developing need-based technologies. It has developed two high yielding varieties of bitter gourd, multi-crop dryer, and juice from black berry.

Patuakhali Science and Technology University (PSTU) has so far developed nine high yielding varieties of different fruit species.

Research at other Government Organizations

National Institute of Biotechnology (NIB) is a very particular institute with a mission to create an institutional space for research, technology transfer and human resource development toward developing eco-friendly biotech products to ensure peoples' welfare. It has a vision to create a strong infrastructure both for research and commercialization ensuring a steady flow of bio-products, bioprocesses and new biotechnologies. It also serves the country as a coordinating center of biotech research and promote awareness on biotechnological innovations and technologies that will engage, excite and trained up young people about biotechnology regarding its immense potential to heal the sick, feed the hungry, restore the environment, and fuel the economy.

Rural Development Academy (RDA) is a specialized national institution engaged in rural development training, extension and action research. It also offers post graduate diploma. RDA has conducted a good number of action research covering wide range of areas related to agriculture and rural development. It has developed buried pipe irrigation model in 1982. A model of dual utilization of the same source of water was innovated for irrigation and domestic purposes in water scarce regions of the country. It has also developed solid waste management technology through community approached bio-gas plant and two storied crop production with solar powered irrigation system.

Bangladesh Academy for Rural Development (BARD) conducts training and socio-economic research in rural development since its inception. Research findings are used for training materials by the academy and information materials by the ministries, Planning Commission and policy makers for drawing up development programs. It experimented to use surface water through low lift pumps and ground water through deep tube-wells with the management of village cooperatives on boro rice cultivation. BARD facilitates farming that is managed through a social enterprise involving farmers' organizations.

Research at NGOs

Historically, the non-government organizations (NGOs) started shortly after the 1971 war of liberation, initially for providing relief services and rehabilitation assistance to war-ravaged victims. Since 1971, the NGOs have made significant progress and contributions through their various development programs and projects such as health, agriculture, agrarian reform, irrigation, credit assistance etc. However, there are only a few NGOs in Bangladesh that promote agricultural research and development such as BRAC, RDRS Bangladesh, PROSHIKA, Friends in Village Development Bangladesh (FIVDB) and CARE International.

BRAC has varietal development and screening program. It is operating farmer participatory experiments for technology validation and fast track diffusion of cutting edge agricultural technologies in ecologically adverse regions. It has developed 12 hybrid and three inbred rice varieties, three hybrid maize and 19 HYVs of vegetables.

Rangpur Dinajpur Rural Service (RDRS) in collaboration with farmers experimented on crop improvement, cropping patterns, quality seed production, rice banks, soil fertility, livestock feed, fish production etc. RDRS facilitated farmers in conducting these experiments involving students, scientists and teachers in collaboration with NARS institutes like BRRI and BARI, and universities like BAU, BSMRAU and HSTU through Memorandum of Understanding (MoU). Most important demand led and need-based technologies were piloted for dissemination through the farmer groups.

Research in Private Organizations and Companies

Government and donors not only support public-sector agricultural research, but also extend assistance to private organizations and companies for generation of agricultural technologies. Technologies were developed by private agri-business organizations through in-country research. For example, competing companies not only assess imported cultivars, but also breed vegetables, maize, and hybrid rice in Bangladesh for local and, in some cases, regional markets.

The Government registered 76 hybrid rice varieties submitted by a total of 23 private companies and NGOs during 2000-2010, while it was so extensive that the government registered 22 hybrid rice varieties submitted by 16 agro-companies in only 2019-2020 (SCA, 2020; AIS, 2021). For all non-notified crops, such as maize and vegetables, private companies have introduced hundreds of cultivars whereas only very few from local breeding. As of 2020, there were so far 25 organizations involved in developing agricultural machineries in Bangladesh (AIS, 2021) out of which 21 organizations were private.

BRAC, Lal Teer, and Supreme Seeds have the largest seed research programs (Kabir and Huda, 2009). BRAC has developed a popular maize hybrid from imported lines. BRAC, Lal Teer, and other companies have bred vegetables including bottle, snake, sweet, and bitter gourds from both imported and local genetic materials. BRAC and ACI have bred hybrid rice using materials from the International Rice Research Institute (IRRI) and BRRI. Partex Agro Ltd. has multi-disciplinary crop improvement

research program to develop superior hybrid varieties and also has program on germplasm collection and conservation. Ispahani Agro Ltd. and Apex Biofertilizers & Biopesticides Ltd. are involved in producing and marketing bio-pesticides, bio-based lures and pheromone traps.

Research at International Organization

Bangladesh achieved genetic gain through advanced breeding techniques and exchange of improved germplasm of major staple food crops in collaboration with Consultative Group for International Agricultural Research (CGIAR) institutions. IRRI, CIMMYT and others played a significant role in crop improvement for higher yields and sharing knowledge.

IRRI (International Rice Research Institute)

First international outreach program of IRRI was established in Bangladesh. In the Savar Farm, a government-run dairy enterprise near Dhaka, a set of 303 rice varieties was evaluated in 1965. IR8, the first widely distributed high-yielding semi-dwarf rice variety, was introduced into the country in 1967. Improved and healthier rice varieties, biotic and abiotic stress tolerant rice varieties, climate change adaptation and mitigation, rice-based cropping systems, farm mechanization, improving rice seed systems, public-private partnership in rice breeding, and capacity building in rice science are the main focus of IRRI's research in Bangladesh. Most of the crosses made for developing the varieties of BRRI contained IRRI breeding materials distributed through the IRRI's International Network for Genetic Evaluation of Rice.

IRRI and the Government of Bangladesh have co-developed the 5-year Work Plan in 2018 to address the future challenges and sustainably increase rice production. The priorities identified in the Work Plan are:

- High yielding, short duration and desired grain quality rice varieties
- Biotic and abiotic stresses tolerant rice varieties
- Hybrid rice varieties
- Improving productivity and resilience of coastal agriculture
- Intensification and diversification of the rice-based production system
- Mechanization and post-harvest technologies
- ICT in agriculture
- Rice value chain and policies
- Capacity development

To escape flash flood in haor areas, it is essential to plant crops early and harvest by March or latest by early April. This requires developing varieties that are tolerant to cold both at the seedling and reproductive stages. To protect Boro rice from cold stress in the haor areas, cold tolerant short-duration HYVs are necessary. A KGF-IRRI-BRRI project is ongoing to develop such HYVs, some prospective breeding materials have been identified very recently which may be released as high yielding varieties.

CIMMYT

CIMMYT has worked together with Government and other institutions over the years since it established an office in Bangladesh in 1982. The substantial support that CIMMYT provided during the 1980s and 1990s was almost entirely given to develop and promote wheat production in the country through germplasm provision, infrastructure development, agronomic research and training. During the 2000s, the support was increased, and the emphasis was given on farm mechanization and conservation agriculture, maize improvement and training, agricultural databases, environmental concerns in intensifying cereal systems and fodder provision for livestock.

A substantial amount of CIMMYT wheat germplasm was imported for wheat and maize Research in Bangladesh to test and incorporate into the breeding program. These were used in the development of 34 wheat varieties so far released in Bangladesh. Large amounts of crop and soils management research programs for wheat was conducted jointly by BWMRI (formerly WRC of BARI) and CIMMYT. CIMMYT made important contributions during the 2000s to the expansion of maize production through the provision of germplasm, strengthening hybrid-based maize breeding and crop management research in Bangladesh. Almost all 19 maize hybrids were released by BARI and BWMRI as of 2020 containing CIMMYT maize lines, and there is significant use of CIMMYT maize by emerging private breeding companies. BRAC released one maize hybrid, Uttoron, from CIMMYT inbred lines (www.cimmyt.org).

Food and Agriculture Organization

Food and Agriculture Organization (FAO) supports for the control of animal diseases. Bangladesh is prone to different types of animal diseases, which seriously affect the livelihoods of poor families and threaten public health. Main efforts focused on enhancement of surveillance and improvement of biosecurity and hygiene practices in backyard and commercial farms and in live bird markets. The country received important support to upgrade its veterinary services and promote public-private partnerships for preventing and controlling Highly Pathogenic Avian Influenza (HPAI) and other emerging infectious animal diseases. It also helps promote and support the One Health Approach to combat human and animal diseases (www.fao.org).

In fact the organization is involved in many dimension in promoting country's farm growth since its commencement. Presently FAO's assistance in Bangladesh is aligned with the country demand and vision, focusing on four priority areas: (i) reduce poverty and enhance food security and nutrition (ii) enhance agricultural productivity through diversification/intensification, sustainable management of natural resources, use of quality inputs and mechanization (iii) improve market linkages, value addition, and quality and safety of the food system and (iv) further improve technology generation and adaptation through better farmer-extension-research linkages.

CONSTRAINTS IN AGRICULTURE

Agriculture has been functioning as a catalyst since long for sustainable development and growth of the country's economy. But it is facing many constraints and challenges with a variable level of magnitude. There remains resemblance as well as disparity in nature of constraints among the sub-sectors: crops, fisheries and livestock and these constraints impact on their respective growth. However, in all the cases, climate vulnerability and socio-economic factors are bagging huge consequences. Although the fisheries and livestock sub-sectors are labor intensive, they generate income very fast and contribute significantly to poverty reduction, foreign currency earnings, and employment generation for poor and marginal people. The crop sub-sector is experiencing highest penalties in the form of reduced or no harvest due to the impact of climate changes, which are threatening livelihood and nutrition security. Whereas the livestock subsector is constrained due to poor quality feed, inadequate breed and disease outbreaks. The increasing population has been putting an additional load continually on the dwindling natural resource base to produce required volume of food, which has accelerated further degradation of natural resources. There is an increased need for food production to feed the 184 million projected population in 2030, 197 million in 2040 (Bokhtiar *et al.*, 2023).

Constraints in General

The country is confronting with severe hurdles like mounting population in context of scarce land mass, loss of arable land to non-farm activities and inadequate scope of employment opportunities in the farm sector. It is evident that arable land has been shifting to non-farm activates at the rate of 0.73% annually (Hasan *et al.*, 2013). The loss of farmland to urbanization means an increase in environmental problems like degradation of air quality, weak transportation, loss of critical habitat and green space, and degradation of water quality. The spread of cities/towns alone consumes enormous tracts of farmland due to growing industrialization and development of various infrastructures. In the long run, the country may permanently lose its food security, leading its poor population more vulnerable to volatile international commodity prices (Financial Times, 23 January 2023).

The research and development efforts have proved to make substantial dividend in yield as well as production. However, similar investment was limited to the non-staple foods and deserved immediate attention particularly, non-cereal and non-crop sectors in agriculture. Albeit, the productivity of many diversified crop has increased, it has not reached up to larger scale of production due to competing land use induced by reduction of cultivable lands and natural resources.

Soil degradation is undermining the long-term capacity of irrigated and rain-fed agro-ecosystems. Stress on land and water are further magnifying the issue of resource constraints to food production. Impact of intensive rice cultivation is that the resource base for agriculture is shrinking. Failure to confront this problem will leave Bangladesh

with low agricultural yields, reduced areas of good agricultural land and high expenditures on modern agricultural inputs to offset loss of land fertility.

Post harvesting losses annually stand at $2.38 billion per year, a loss that can be salvaged through agro-processing. Limited road infrastructure and electricity supply are the major barriers for developing agro-processors in the country. As a result of weak supply chain relationships, farmers face considerable discouragement in undertaking large-scale cultivation, thus making procurement limited to availability of goods in the market. In the last 2-3 decades, production of potato in Bangladesh increased with the cultivation of high yielding varieties. But the potato growers are stuck with surplus stocks and low exports. With an annual average demand of around 7.0 M t, the country witnessed a surplus of about 4.0 M t, most of which is wasted due to lack of sufficient storage facilities.

Diversity of agricultural production is getting narrower to a few crops like rice, potato, maize, some vegetables and fruits. Recently, jute is facing a stiff competition due to the fact that jute land is equally suited for growing rice, and rice is commanding a record high price in the home market. The price of jute was not very attractive compared to other competitive crops. Even though, existing wheat varieties in Bangladesh are high yielding, area and production did not increase sufficiently to match the growth in the human population. Moreover, many wheat crops were replaced by different rabi crops such as potato, boro rice, maize and different short-duration vegetables.

In spite of a large number of improved varieties, narrow genetic base is identified as the main constraint for spectacular genetic gains in pulses. The domestic production of edible oil can only meet about 20% of the country's annual demand and rest 80% is imported which costs more than BDT 20 billion, although the production has increased. Constraints involved in the oilseeds sector of Bangladesh are related to climatic variability, scancity of quality seeds, competition with other crops, production and post-harvest management and market access.

Skill gap in scientists is evident in some specific disciplines due to poor share of PhD scholarships. It is primarily due to a poor share of technical assistance in the agricultural ADP. The quality intake of postgraduate students is affected due to the variation of requirements in grade/GPA/class obtained from their previous degrees.

Climate vulnerability

Bangladesh is the seventh most climate change vulnerable country. As per Climate Resilient Index 2021 (Amin, 2021) based on 20 years data analysis (2000 to 2019), the country lost 11,450 people, incurred economic losses worth US$ 3.72 billion and witnessed 185 extreme weather events during the period due to climate change. In terms of economic losses, Bangladesh ranked fifth, which indicates that the country's economy is consistently at risk due to climate catastrophes, impacting badly on human health, education, agriculture (crops, livestock and fisheries) and ecosystems. The country is placed at the 13th position among countries that faced most losses in 2019

due to various climatic events. It is predicted in the Eighth Five Year Plan (2021-2025) that availability of fresh water will decline and natural hazards like cyclone, storm surges and coastal flooding will increase in future. The salinity level of groundwater along with the surface water will rise rapidly due to climate change induced sea level rise. The local communities and their livelihood will be greatly vulnerable due to climate change (BPC, 2020b).

Storms and other disasters like salinity and waterlogging in coastal areas along with early monsoon and late flooding affect severely the agricultural production. Storm is one of the major devastating factors as noticed from Sidor-2007, Nargis-2008, Aila-2009, Bulbul/Fani -2019 and Amphan 2020. Cyclone Bulbul affected around 722,674 people in Satkhira, Khulna, Bhola, Bagerhat, Patuakhali, Barguna and Pirojpur districts. More than 108,000 houses and 117,000 hectares of cropland were damaged along with significant destruction of several embankments. The Need Assessment Working Group (NAWG, 2020) reports that the fisheries sector counted a loss of US $5.5 million as some 11,223 hectares of ponds and ghers (fish farm) were affected. While the initial livestock damage was US $285,000. Besides, in May 2019, strong winds and tidal surges breached 32 kilometers of river embankments, which created localized inundations and damaged crops, livestock and fisheries (www.tbsnews.net).

Increase in surface air temperature is most prominent in Bangladesh. An increasing trend and temporal variation in the mean seasonal temperature is observed within 0.4 - 0.65°C during the past 40-year period. Although the winter season experiences the minimum rainfall, historical trend shows a positive inclination in 27 out of 32 rainfall observatories of the meteorological department. The normal trend of riverine flood (or monsoon flood) is affected by the climate change related phenomenon, especially due to change in the frequency and intensity of extreme rainfall event, which may subsequently increase the intensity and duration of flood. Riverbank erosion due to monsoon flooding damages farms land, houses and other infrastructure regularly. Low rainfall and extreme temperature events (high and low) because of climate change affect agricultural production and livelihood leading to poor harvest and threatening livelihoods of people. At present, western parts of Bangladesh are periodically affected by droughts in winter months. Since the temperature will rise and a possibility exists that the winter precipitation will decrease further, which in turn will decrease topsoil moisture content leading to severe moisture stress (Nishat and Mukerjee, 2013).

The World Bank (2021) have also reported some features of Bangladesh climate vulnerability. It projected that average temperature rises in Bangladesh are broadly in line with that of the global average. The highest emissions pathway projects a rise of 3.6°C by end of the century, above the 1986-2005 baseline. Rises in minimum and maximum temperatures are considerably higher than the change in average temperature and are concentrated in the period of December-March. Increased frequency of periods of prolonged high temperature is a major threat to human health and living standards, particularly in urban environments and for outdoor laborers. Livelihoods in coastal zone and inhabitants of many poorest communities are under threat from saline intrusion and degrading natural resources linked with climate

change. Flash, river and coastal flooding are likely to be exacerbated by intensified extreme rainfall, tropical cyclones and associated storm surges, placing lives, infrastructure, and the economy at risk. The agricultural sectors will face reduced yields driven by temperature rises in growing season, saline intrusion, increased drought frequency, flooding and water congestions (The World Bank, 2021). The rise in temperature and erratic weather patterns leading to unpredictable rainfall and floods have already impacted badly on availability of quality fresh water. The devastating effects of global warming will lead to a far reaching and adverse consequences on agriculture (crops, livestock and fisheries), public health and livelihood (Raza and Inoye, 2022).

Fragile ecosystems

Recently the Government of Bangladesh has adopted Bangladesh Delta Plan 2100 (BDP, 2100), which is a visionary document wherein long-term, integrated, and holistic vision of water and land management throughout the country is integrated (BDP 2100, 2018). It supports the country's long-term development in the context of prevailing and anticipated opportunities and risks that emerge from the interface between water, climate change, and human activity. The vulnerable areas of country's 64 districts have been compartmentalized into six ecological zones based on hydrological characteristics and climate risks. As per BDP 2100, the country's six ecological hotspots are identified as fragile ecosystems facing severe challenges particularly in health and agriculture, which require urgent interventions to address these challenges. It has also recognized 58 extremely vulnerable districts, which are prone to climate change risks. However, a brief on the hotspots including constraints the agriculture sectors encounter is outlined below:

Urban areas

Farming in this area is constrained by water congestion and stagnancy with poor crop yield. The agriculture and water systems contain pollutants like heavy metals. In these areas, poor drainage system causes inundation of the city streets frequently and waterlogging of adjacent crop fields. There also prevails inadequate cleaning of waste and refused disposal, which results in outbreaks of water-borne diseases. In general, these areas are characterized by inadequate water supply and poor sanitation, hygienic conditions and practices.

Barind ecosystem

The Barind ecosystems covers the most parts of the greater Dinajpur and Rangpur under Rangpur division, and Pabna, Rajshahi, Bogra, Joypurhat and Naogaon districts of Rajshahi division. The Barind ecosystems is believed to have been evolved from tectonic uplift and/or exists as an erosional geomorphic feature. It represents the northwestern region of the country and recognized as drought prone, where depleting ground water in dry months significantly reduces crop land areas and cropping intensity. The ultimate effect is the crop failure, which causes poor harvest and accelerate poverty, seasonal unemployment and food insecurity. However, many

public and private sectors' efforts have impacted positively on local farm productivity with intervention like irrigation facilities coupled with adoption of high value fruit crops and vegetables.

The major problems of agriculture in the barind ecosystem are drought, ground water decline, degradation of forests, low soil fertility, reduction of pasture lands, loss of fish habitats etc. The groundwater level (GWL) is receding continually indicating overuse of groundwater for irrigation on the one hand and inadequate recharge due to low rainfall on the other. A thick top clay layer (Barind clay of Pleistocene age) is one of the major obstacles against good tillage for crop establishment and growth and groundwater recharge. Depletion of ground water severely affects crops not only in the dry season but also in some years in the Kharif season so that transplanting of T. Aman rice is delayed and hampered resulting in reduced yield. The Barind households encounter problems with livestock feed shortages both in the dry and wet seasons. Most ponds are seasonal due to drought that limits fish production throughout the year. Use of chemical pesticides destroys aquatic biodiversity and leads to aquatic pollution.

Coastal ecosystem

The coastal areas consist of 19 southern districts, viz. Jashore, Narail, Gopalganj, Shariatpur, Chandpur, Satkhira, Khulna, Bagerhat, Pirojpur, Jhalakati, Barguna, Barishal, Patuakhali, Bhola, Laxmipur, Noakhali, Feni, Chattogram and Cox's Bazar (Abu *et. al.*, 2003). The coastline is composed of the interface of various ecological and economic systems, including mangroves (the world's largest mangrove forest, called Sundarbans), tidal flats, estuaries, sea grass, islands, accreted land, beaches, a peninsula, rural settlements, urban and industrial areas and ports. The exposed coastal area is most vulnerable to natural disasters like cyclones, tidal surges, strong salinity etc. Over 30 million people living along the coast are relying heavily on rivers, tube wells, and ponds for washing, bathing, and drinking water. They are now affected by varying degrees of salinity, being associated with high rates of miscarriage, and increased risk of eclampsia and gestational hypertension among pregnant women along with inadequate harvest, poor cropping intensity and fewest means of livelihood.

Soil salinity in drier months (February to May) affects crop growth, which reduces yield and in severe cases causes total yields losses in the coastal areas. Variability and uncertain rainfall, cyclone, storms etc. delays sowing/transplanting and flooding damages Aus and Aman rice crops. Late harvest of T. Aman rice with short winter season restricts Rabi crop cultivation. Sea level rise due to climate change results in flooding and salinity intrusion, and thus reduces grazing grounds and fodder production for livestock. Flooding, waterlogging, erosion and siltation also result in the scarcity of free grazing area. Increase of salinity coupled with inadequate water management affects freshwater aquaculture. Drought and tidal waves, rain and flood affectfish culture round the year. Upstream water withdrawal and siltation facilitate reduce reservoirs for fish culture.

Haor ecosystem

The haor basin spreads over Sunamganj, Habiganj, Moulvibazar Sylhet, Kishoreganj, Netrokona and Brahmanbaria districts. These areas receive surface runoff water from rivers and canals to become vast stretches of turbulent water during monsoon and turned into a vast water body resembling an inland sea and remain flooded for seven to eight months during the rainy season. The available cultivation days has been reduced than earlier, affecting progressively rice production and resulting in increased poverty and heightened food insecurity risk with safe drinking water scarcity. In parallel, the area is experiencing frequent flash floods that causes loss of crops, lives, fisheries and livestock, and contamination of water sources and unhygienic sanitary conditions. In rainy months, limited livelihoods options, and shortage of livestock and poultry feeds become widespread, and people have to rely non-farm enterprises. In recent years, the basin has become shallower leading to the formation of reeds and sedges through gradual sedimentation. Nonetheless, this has resulted in providing enough food and shelter for fish and other aquatic fauna.

Heavy rainfall as well as onrush of water from the upstream Meghalaya hills in India recurrently inundates cropland of the *haor* areas in Bangladesh. An onrush of excess water often breaks embankments in many places and inundates vast cropland and homestead areas. Water coming from the Mona, Jhuri and Kushiara rivers and water from canals of hill slopes causes flash floods and croplands go under water for varying periods. Flash floods, when coupled with heavy rainfall, cause severe and prolonged flooding. On the other extreme, prolonged droughts also occur in *haor* areas. The main source of irrigation is surface water, but the water bodies dry up during winter and pre-monsoon forcing the farmers to keep their lands fallow. Floods, droughts, high temperature, flash floods, etc. are predicted to be more frequent and intense in the *haor* areas, expected to severely damage crops, livestock and fisheries. The main challenges in livestock rearing in *haor* areas are scarcity of grazing fields, insufficient livestock care services, lack of feeds and fodder etc. There are not enough fish pass structures in flood control embankments and road etc. to benefit fisheries. On the socioeconomic front, agricultural production in *haor* areas is constrained by several factors. A major problem is the scarcity of agricultural laborers for harvesting Boro rice. Farmers have to put up with high prices of inputs (fertilizer, seed, labor etc.) and inadequate transportation facilities for their produce.

Charland and riverine ecosystems

The charlands are by products of hydro-morphological dynamics of the rivers and the land masses are formed through accretion of sedimentation of huge amounts of sand, silt and clay over time carried by the three rivers namely, Padma, the Meghna, the Brahmaputra-Jamuna (Sattar and Islam, 2010). River erosion is a common disaster occurring around charland and riverine ecosystem, which causes a good number of households, on average, become homeless each year. Also, it has resulted into a loss of productive lands and other natural resources of the riverine households, and pause associated threat to livelihoods and food security, the area is ultimately recognized as a farming constrained area. Its productivity is usually low, particularly in the newly

accredited charland due to poor soil fertility, especially poor in organic matter, and inadequate intervention. The greatest spread of chars exists in the Jamalpur district, followed by chars in Kurigram district. The Bay of Bengal adjacent to several districts of Barishal and Chattogram divisions has also created significant char areas. The Noakhali district possesses the greatest number of such coastal chars followed by Patuakhali and Bhola districts.

Quite often early flood occurs in *char* areas, which damages the almost mature Boro rice. Severe drought also occurs in the winter season when limited irrigation facilities affect Boro rice. Cropping systems are also unstable. Migration of agricultural laborers is significant during both planting and harvesting times due to high demands in the mainland. In peak flood periods, shifting cattle to high land such as an embankment is a problem for *char* households, while lack of fodder and shortage of funds compel farmers to sell this important asset at nominal prices. There are outbreaks of various livestock and poultry diseases in the wet season. Veterinary doctors are rarely available in the *char* areas. Late rain impacts brood fish maturation, immature eggs and sperms lower growth rate, fish disease infestation occurs. Low water level in rivers, canal etc. increases fishing pressure, which causes an indiscriminate catching of broods and juvenile fish. High temperature causes mortality of spawn, fry and fingerlings.

Hill ecosystem

The Chattogram Hill Tracts is geographically distinct from other parts of Bangladesh and is mainly characterized by very steep and rugged mountainous terrain. These hills are situated in greater Sylhet, Chattogram and the Chattogram Hill Tracts (CHT). In Moulvibazar, Habiganj and north-eastern part of Sylhet, there are hills or hillocks covered with grasses and trees. All the mountain ranges of CHT are almost hogback ridges. These are steep and most of the ranges have scarps in the west with cliffs and waterfalls. There is a huge network of trellis and dendritic drainage consisting of some major rivers draining in to the Bay of Bengal. Most of the population lives in small, scattered habitats in vicinity of the ecosystem, making technology dissemination difficult. Climate change and related weather events profoundly impact badly on the psychological well-being and mental health conditions of the CHT population. Landslide, soil erosion particularly from impotent 'Jhum' cultivation, poor irrigation infrastructure and inadequate marketing facilities are the limiting factors of farm growth of the ecosystem.

Long dry spells leading to severe crisis of water coupled with very poor irrigation system limit crop production in the hilly areas. Inadequate HYVs of crops for the *jhum* system hinder cultivation of hilly areas. Increasing population pressure has resulted in the shortening of the fallow period of jhum cultivation to as little as 1-2 years with a sharp decline in *jhum* productivity. The most serious problem resulting from pineapple gardening and growing of some root crops such as ginger and turmeric is the direct exposure of the soil surface to heavy downpour and surface runoff gradually diminishing harvests of the concerned crops. The main challenges in livestock rearing are lack of quality veterinary facilities and physical infrastructure and insufficient scientific and technical innovations. Storage facilities including cold storages are few

and very poor marketing facilities exist in the hilly areas. Farmers have poor access to agricultural inputs, technologies, extension services, marketing etc. due to remoteness.

Natural resources degradation

Resource degradation is the deterioration of the environment through depletion of resources like air, water and soil, ecosystems destruction and the extinction of wildlife (Jouanjean *et al.*, 2013). Bangladesh faces a series of environmental problems including deforestation, land degradation, riverbank erosion, air pollution, water shortage and contamination, loss of biodiversity and climate change bound farm discomforts. Deforestation, with loss of forest cover, is responsible for soil erosion and loss of fertile top soil decreases agricultural productivity. The intensive methods of land use along with continual use of chemicals to elevate production is polluting land, soil and water and also contaminating food systems. Unscrupulous underground water withdrawal for irrigation accelerating aquifers depletion coupled with high rate of evaporation may result in a severe water scarcity if not replenished. The mindset of using firewood as fuel without thinking alternate less environment damaging sources is drawing detrimental effects to the long-term environmental sustainability resources and unplanned resource use is likely to result in environmental degradation (Giasuddin, 2019). The costs of environmental degradation and natural disasters are predicted to rise over time, compounded by higher heat, humidity, and health impacts (The World Bank, 2022).

The country's natural resources are progressively degraded due to concerted efforts of natural disaster, population growth, poverty, devious farming activities, and other human interventions like embankment, physical infrastructures, roads and highways, housings, ghers, polders and many more. Soil erosion and over logging are negating forests, wetlands and farmland. The rise in industrial production is also taking its toll on the environment, for instance, untreated waste water is being dumped into the country's rivers and associated water bodies and further contribute to heavy metal contamination in food chain.

The farmland particularly lowland is regularly flooded and making unavailable for use to harvest more than a crop in a year. The unpredictable climatic conditions accelerate natural resource degradation in many dimensions like flood, moisture stress, extreme temperature, salinity intrusion, pest outbreak. Consequently, these increase the risk of frequent food shortage and limits livelihood which could be intensified in future.

The poverty and environmental degradation have close interlinks and reinforce each other. Decline in agricultural productivity on degraded lands then triggers poverty, which in turn, forces many farmers to continue degrading their land further to extract subsistence output.

Socio-economic factors

Socio-economic factors such as income, education, employment, community safety, and social supports significantly affect society well-being and livelihoods of a locality. As such these factors affect people's ability to access to food stuffs, farming opportunities, healthy choices, medical care, housing, manage stress, technologies etc. The variables such as gender, age, years of schooling, service area, operational farm size, farm machineries, cow-shed, electricity, radio, mobile phone, television, computer, bicycle, motorcycle etc. affect farmers' production system and income. Gender disparity is seen as major impediment, which discourages total labors necessary for farm production and income. A gender parity and key role of small farm holding in farming is evident (Susmita and Mondal, 2022). Residences of increasing population of the country are expanding at the cost of agricultural land followed by urbanization and industrialization.

In farming, many challenges from socio-economic point of considerations influencing farm growth (Salam, 2022) are noted. Some of key challenges include:

i. inadequate sustainable marketing system, insufficient quality inputs supply,
ii. meager private investment in research,
iii. lack of public-private joint venture,
iv. inappropriate farm mechanization,
v. poor linkage among stakeholders,
vi. poor consumers' awareness building through scientific broadcast,
vii. inappropriate farm products distribution channel from producer to consumer,
viii. disproportionate agro-processing industries,
ix. scarcity of farm labors,
x. poor pollution mitigating initiatives,
xi. insufficient study on farm products commercialization in the export markets,
xii. poor access to easy credit and
xiii. farmer's rigidness to accept novel technologies.

Sectoral constraints

Crops sub-sector

Crop is one of the major sub-sector with the key role in economic development and food and nutrition security. The constraints of this sub-sector are-

i. poor natural resource base,
ii. low crop productivity,
iii. climate vulnerability,
iv. inadequate availability and supply of quality inputs ,
v. inadequate extension services,
vi. high post-harvest losses,
vii. inappropriate market access and dominance of market intermediaries,
viii. poor agro-processing, value chain, and value addition,
ix. lack of easy credit to smallholders,

x. shortage of farm laborers and slow mechanization,
xi. resurgence of pests and diseases, and trans-boundary diseases and
xii. yield gap and adoption lag etc.

It is highlighted in the National Agriculture Policy 2018 and 8th Five Year Plan (2021-2025) that incessant population soaring continually puts an extra burden on the crop sub-sector affecting productive capacity and expanding food and nutrition deficit. Other constraints the sector is encountering include poor employment opportunity, indiscriminate use of pesticides, water scarcity and management challenges, environmental pollution etc. which affect the agricultural production system.

Livestock sub-sector

Livestock farming bears specific advantages over crops, fisheries and forestry, as livestock require less land and are least influenced by seasonal variations of weather. However, animal disease alone causes about 50% death of all livestock population. The constraints that the sub-sector is facing include, among others,

i. wide yield gap between the traditional and intensive and semi-intensive farming,
ii. lack of availability of high yielding breeds and technological know-how
iii. maintaining quality breed,
iv. animal diseases and diseases outbreak,
v. lack of quality assurance,
vi. inappropriate market structure,
vii. inadequate coverage of animal health services,
viii. lack of space and physical security of animal resources, and
ix. low investment in livestock research and its poor management (Ali and Hossain, 2016).

In addition, anestrus, inbreeding and repeat breeding are also recognized negating this sub-sectoral growth. It is evident from the regional workshops that overall feed, breed and disease management are the most significant challenging factors limiting growth and development of livestock.

Fisheries sub-sector

Specific constraints refuting the growth of culture fisheries include

i. poor physical condition of resources (specially water quality and quantity),
ii. low input culture system,
iii. lack of diversity in culture practices and species,
iv. poor supply of quality fish seed,
v. high feed cost,
vi. volatile market price and marketing,
vii. inadequate regulatory mechanism,
viii. disease incidence,
ix. inadequate credit facilities,

x. inadequate infrastructure for pre-production, production, post-harvest and processing facilities and
xi. shortage of skilled manpower (BBS, 2022).

In inland capture fisheries, seasonal fishing, depleted fish habitats and stocks in natural waters, issues related to tenural and leasing rights, obsolete technology used for harvesting and low capital infusion are some of the significant limiting factors. Major constraints impacting on the growth of marine fisheries include limited scope for expanded fishing in territorial waters, weak regulation, inefficient management and prevalence of traditional fishing practices. Lack of updated data on fish stock and fishing grounds hinders this sub-sector to frame out appropriate policies and strategies. The country lacks ability to collect high valued fishes of marine aquaculture beyond 40 m depth. Besides, inadequate infrastructures especially, regarding fishing harbors, landing centers, cold chain and distribution systems, and poor processing and value addition, wastage, traceability and certification, shortage of skilled manpower , etc. are the daunting factors constraining the fisheries growth and development (BBS, 2022).

METHODOLOGY

In outlining an agricultural research vision considering the present and future constraints, it must be aligned with the country's Vision 2041. This also requires consultation with various stakeholders working in agricultural sectors at grassroots, regional and national levels to grasp maximum pertinent issues to be integrated into the vision documents. Usually, under Bangladesh context, a top-down approach is followed that does not pay due attention to the voices of ground level stakeholders. Consequently there remains always a possibility of missing the issues of the real context resulting in a weak planning document that cannot fully address the constraints of the agricultural sectors. Avoiding this serious limitation a number of measures were undertaken in formulating this visionary document as mentioned below.

Sharing outlines of Bangladesh Agricultural Research Vision 2041

At the beginning, a stakeholder meeting was organized by the Project Implementation Unit- Bangladesh Agricultural Research Council (PIU-BARC) on behalf of BARC with the Executive Chairman in the chair wherein Director Generals and Director (Research) of NARS institutes and Member Directors of BARC, and representatives from Agricultural Universities, NGOs and private sectors attended. The meeting traced out local level researchable issues of crops, livestock and fisheries sub-sectors, which was outlined by the Director, PIU-BARC under NATP-2 followed by a discussion. The approach was revised after suggestions from the participants.

Formation of Thematic Group

Before organizing meetings, local potential participants were identified and listed down. Later, the participants were grouped according to sub-sectors. In each of the group, representatives from extension service was obviously included with a view to grasp local challenges and to recommend follow up priority research. A number of online meetings were organized with all group members as participants and briefed the purpose and prospect of workshops. It was requested in the workshops to nominate lead and co-lead officers from the participating members and also get any potential changes in the group. In this meeting, manuscript preparation outlines and related tables were presented in front of the stakeholders for their input and these were updated addressing their suggestions. The improved formats and tables were shared with the team members for preparing PowerPoint presentations. They were also asked to contact PIU-BARC in case of any clarification or support required towards a successful presentation through PowerPoint in the regional workshops.

Altogether eight workshops were planned and for each of those workshops PIU-BARC, NATP-2 management formed five groups for the purpose of priority setting in five fields under each sub-sector. Each group was led by a senior professor/scientist/ extension personnel. Each group was composed of 5-10 members from universities, NARS institutes, DAE, BADC, NGOs etc. The groups were provided with specific formats and tables for manuscript preparation and PowerPoint presentation.

Identification of Constraints and Research Issues

Identification of location specific research issues for three sub-sectors (crops, livestock and fisheries) is a major task in preparing the Bangladesh Agricultural Research Vision 2041. To that end sub-sectorial studies were planned and executed embracing the priority setting exercise. The PIU-BARC through National Agricultural Technology Program Phase II Project (NATP-2) supported by the World Bank and International Fund for Agricultural Development had organized eight regional workshops in eight divisions, namely, Barishal, Chattogram, Dhaka, Khulna, Rajshahi, Rangpur, Mymensingh and Sylhet with an objective to identify constraints and researchable priority issues for each of crops, livestock and fisheries sub-sectors. Every group leader made PowerPoint presentation with headings viz., introduction, situation analysis, possible interventions, existing priority research areas, proposed priority research areas for short/medium/long term with a priority ranking as high, medium and low, and way forward.

The five areas of group presentation for crop sub-sector were namely: (i) Crop Improvement, Genetic Resources and Conservation, (ii) Crop Production, (iii) Crop Protection, (iv) Farm Mechanization, Irrigation and Water Management, Post-harvest, Agro-processing, Value Addition, and (v) Technology Validation and Adoption. The five areas for fisheries sub-sector was namely, (i) Enhancement of Fish productivity and production (Inland, Coast and Marine), (ii) Fisheries Protection and Conservation; (iii) Fish and Shrimp Harvesting, Post-Harvest and Processing Management; (iv) Fish Germplasm Collection, Characterization, Conservation and Improvement and (v) Technology Validation and Adoption. While that for livestock subsector was (i) Genetic Resources, Conservation and Improvement of Livestock and poultry, (ii) Disease Management (Epidemiology, Control and Management of Farm Animals and Poultry Diseases), (iii) Feeds and Fodder production for Safe Livestock, Poultry Products and Dairy Food; (iv) Beef, Dairy And Poultry Based Product Processing and Value Chain (Small and medium industry) and (v) Technology Validation and Adoption.

The group leader had presented the paper with contents as per format provided by PIU-BARC. A blank comment sheet was distributed among the participants for their comments and suggestions in respect of potential priority researchable issues. An open discussion was made after each presentation. The participants had opportunities of providing suggestion/comments orally and or in writing using the supplied comment sheet. Considering the eight workshops, on an average approximately 43% of the participants were from different extension agencies, 28% from research institutes, 24% farmers and entrepreneurs and the rest 6% were from universities, NGOs and other organizations totaling 2,413 participants as shown in the Table 3. In these workshops, all personnel from NATP-2 including Director, and Member-Directors of BARC and Director/specialists of KGF and BARC were present and contributed in drafting vision document. The group leaders and members were further contacted to provide information for filling gaps.

Table 3 : Share of regional workshop participants

Sl no.	Division	Research organization	DAE/DLS/ DOF	University	Others (Ministry/ NGO/ Farmer/ Private sector/ Entrepreneurs)	Total
1	Khulna	79	100	5	66	250
2	Rajshahi	69	87	6	62	224
3	Barishal	90	134	19	61	304
4	Chattogram	86	145	15	61	307
5	Rangpur	73	136	15	105	329
6	Sylhet	51	111	28	74	264
7	Mymensingh	80	114	33	72	299
8	Dhaka	97	151	18	62	328
9	National Validation Workshop	55	35	12	06	108
Total		**680**	**1013**	**151**	**569**	**2413**
		(28.18 %)	**(41.98 %)**	**(6.25 %)**	**23.58 (%)**	**100**

Stakeholder Workshops

The information gotten from the eight regional workshops were compiled, analyzed and used in preparing a draft vision document. Later, the document was presented in the national stakeholders' workshop held at BARC organized by PIU-BARC with participants from MoA, MoFL, DAE, NARS institutes, universities, BADC, DLS, DoF NATP-2, KGF, NGOs and relevant organizations to finalize the vision document for crops, livestock and fisheries sub-sectors and then combined. Also, an open discussion was carried out to receive comments and suggestion from the participants either orally or in writing following a prescribed format. Later, the oral and written suggestions and recommendations from the day-long workshop were incorporated and the vision document was then finalized.

Synthesis of National Policies and Plans

For collection of secondary information on various policies, plans and strategy documents related to Bangladesh agriculture (crops, livestock and fisheries) were reviewed and synthesized. There are different legal arrangements for the sub-sectors, based on which different organizations are carrying out and manage their functions. Key consulted documents include Sustainable Development Goals - 2030, National Agriculture Policy 2018, Bangladesh Delta Plan 2100, National Agricultural Mechanization Policy 2021, Vision 2041: Perspective Plan of Bangladesh (2021-2041),

Eighth Five Year Plan (20213-2025), Agricultural Research Vision 2030 and beyond: Research Priorities in Bangladesh Agriculture, 3rd Country Investment Plan, National Fisheries Policy 2006, National Shrimp Policy 2014, National Fisheries Policy 2017, Marine Fish Harvesting Policy 2022, National Livestock Development Policy 2007, National Poultry Development Policy 2008, among others. The delineated research issues in the mentioned documents were critically examined by elite professionals and pertinent ones are included in the draft vision document.

Validation of Draft Vision

Eventually, a national level day-long validation workshop was organized by PIU-BARC where high officials from Ministry of Agriculture, Ministry of Fisheries and Livestock, senior researchers, academicians, policy planners and extension personnel from more than 25 government and nongovernment organizations attended the workshop. The inputs received orally or in writing from the workshops were integrated in the document. In such a way, the researchable issues for vision document were identified for all sub-sectors based on the existing problems and anticipated farm challenges according to the thematic areas. Following the inputs of regional workshops, adopted policies and action plans and audience responses, a Strategy and Framework is also sketched as an approach to achieve research vision.

AGRICULTURAL RESEARCH PRIORITY

In pursuance of contextual changes in various dimensions, it is necessary to revise the existing agricultural research vision prepared in 2011, recognized as Research Priorities in Bangladesh Agriculture: Vision 2030 and Beyond in 2011 (BARC, 2011). The current document is regarded as Bangladesh Agricultural Research Vision 2041. This is framed as a concurrence text considering contemporary government policies and strategies document adopted by the government. The main features of the document are to ensure nutrition security, create employment opportunities, sustain natural resources, elevate income and keep youth and women in the sector as a decent profession through agricultural commercialization through supportable innovations following a suitable vision. Similarly a cost effective, safe and competent agricultural production systems, and managing natural resources sensibly are urgent and critical research areas with a new visualization towards transforming of agriculture through Evergreen Revolution instead of mere 'Green Revolution'. Under these backdrop, the agricultural research vision 2041 is drawn for each of the sub-sectors of agriculture.

Vision: Agricultural research for technology innovations on climate resilient, cost effective, safe and nutritious food production system and efficient natural resource management.

Mission: Harness potential of science, technology and innovations for higher and sustainable agricultural productivity to meet demand of country's increasing population by 2041.

Aims:

- Generate demand-driven, safe, sustainable and profitable technologies in crops, livestock and fisheries sub-sectors of agriculture.
- Innovate technologies for agricultural diversification, yield gap minimization and nutrition rich safe and climate resilient food production systems.
- Develop cost effective farming system technologies and create employment opportunity.
- Document and disseminate research outputs to stakeholders
- Formulate strategies to improve and sustain farm productivity without undermining natural resources (soil, water, biodiversity and forests).

The thematic areas of the three farm sub-sector viz. crops, livestock and fisheries of the research vision for enhancing livelihood of the substantial population are sketched separately.

Crops Sub-sector

Bangladesh has made a noteworthy progress in food production during the past three decades and the country has been transformed from a food-deficit into an almost food sufficient country. Nevertheless, it is a great challenge to maintain food self-sufficiency for increasing population on a longer term under the situations of climate vulnerability and decreasing arable land accompanied with degrading natural resources. However, opportunities exist to address this issue through

i. development and adoption of stress tolerant, short duration and micronutrients (Zn, Fe) rich crop varieties,

ii. development and up-scaling of climate resilient technologies,

iii. use of efficient cultural practices including fertilizer management, pest management, farm mechanization, cost-effective irrigation system, post-harvest and agro-processing, and

iv. participatory technology validation and adoption.

Taking into account of these points, future research priorities are outlined and elaborated in five thematic areas.

Thematic Area: Genetic Resources Collection, Conservation, Characterization and Crop Improvement

Innovating crop varieties with higher productivity and improving stress tolerance and quality are continuous process to keep pace with the growing food demand. Use of innovative genomic tools and knowledge in combination with conventional breeding and high throughput selection methods could be an appropriate strategy facilitating breed field crops towards desired yield and quality enhancement. Similarly, the use of the cutting edge technologies such as gene editing, marker-based selection, metabolomics, and cell culture techniques should be taken into consideration to stabilize and elevate yield ceiling and also improve nutritional quality of crops. The important priority areas to cover short-, medium- and long-term objectives of crop improvement for the next two decades are summarized as below.

Genetic resource management

- Collection, conservation and characterization of germplasm
- Identification of novel traits: biotic and abiotic stress tolerance, nutrient dense traits etc.
- Improvement of genetic resource management system
- Promotion of GI (Geographical index) crops

Stress tolerance and quality improvement

- Improvement of local germplasm with special characteristics and value
- Development of biotic and abiotic stress tolerant crop varieties

- Development of short duration (early), regular and late maturing varieties, especially vegetables, pulses, oilseeds and fruits
- Improvement of quality: flavor, shelf life, taste, nutrient dense, therapeutic value etc.
- Improvement of resource use efficient varieties

Accelerating genetic gain

- Genomics, phenomics (genome based precision breeding), gene mapping and trait stacking
- Tracing useful traits/QTLs and exploitation with high-throughput selection markers (SNP etc.) and techniques
- Transforming Crop Breeding: Population improvement, genomic selection and speed breeding
- Genetic transformation, genome-editing technology (CRISPR-Cas9) for genetic gains
- Breaking yield ceiling: exploitation of hybrid vigor (heterosis), mutation etc.
- Improvement in physiological efficiency of crop plants

Thematic Area: Soil and Crop Management

Soil health and organic matter has been deteriorating associated with micronutrient deficiencies and tillage bound poor soil physical conditions over time due to higher crop removal and increased cropping intensity. Thus, pertinent research is needed for long-term sustenance of soil health and productivity. In this regard conservation agriculture, which advocates no or single pass tillage, retention of previous crop residues and legume-based crop rotation, is a promising approach to conserve soil moisture and nutrients and reduce production cost. Studies are also needed to develop technology for mitigating heavy metal pollution, greenhouse gas emissions, and increasing nutrient and water use efficiency.

Soil health management

- Sustenance of soil fertility and organic matter
- Improvement of fertilizer use efficiency (nano-fertilizer, neem coated urea etc.) for different agro-ecological zones with an emphasis on fragile ecosystems
- Techniques for soil erosion control
- Characterization of soil microbes and development of bio-fertilizers
- Remediation of heavy metal (As, Cd, Pb) contamination in soil
- Addressing soil and groundwater pollution from surface applied agro-chemicals, industrial wastes and municipal wastes
- Mitigation of greenhouse gas (CH_4, N_2O and CO_2) emission

Crop management and cropping systems

- Improvement of cropping systems for favorable and unfavorable ecosystems
- Innovation of nutrition sensitive cropping systems with pulses and oilseeds

- Crop diversification in cropping systems
- Improvement of cultural practices for innovative cropping systems
- Enhancement of seed replacement rate
- Appropriation of plant growth regulators (PGR)
- Development of scoping for protected, precision and vertical agriculture
- Innovation and promotion of high value and low volume crops for export
- Development of integrated weed management including bio-herbicides
- Innovation of agronomic practices for minimizing productivity gap and ensuring quality seed production, processing and seed standard

Thematic Area: Crop Protection

Pest infestation has increased with time due to intensive cropping, climate change and trans-boundary migration, which in turn, causes huge crop loss. To keep the crop loss under economic threshold level, undertaking preventive measures such as planting of resistant varieties, use of disease-free seeds, balanced doses of fertilizer application and practice of suitable crop rotations are required. The following research areas are considered to develop effective and integrated pest management systems and institutional mechanisms for good and cost-effective production. Also, pest intelligent systems such as early warning and migratory movement of bio-risk agents should be developed at local, regional and national levels for a safe harvest.

Pest and disease management

- Mapping and exploitation of pest resistance using molecular technique
- Development of Bangladesh standard on Maximum Residual Limit (MRL)
- Improvement of IPM and nanotechnology
- Development of ecosystem based location specific pest management system
- Innovation of sensor-based pest diagnosis and pesticide use
- Development, calibration and validation of pest management framework
- Epidemiology of crop pest with climate change interaction

Bio-pesticide development

- Development of bio-pesticide based sustainable pest management
- Appropriation of bio-control agents (pollinators, parasitoids and predators)
- Innovation of sterile insect technology for pest suppression
- Mapping of potential botanicals for pest management.

Monitoring and surveillance

- Pest and disease surveillance, early warning (forecasting) system and pest resurgence
- Assessment of ecological, environmental and economic damage (using remote sensing, GIS technology etc.)
- Population dynamics and biology of major pests
- Digitalization of pests by mapping across eco-systems and regions

Thematic area: Farm Mechanization, Irrigation, and Post-Harvest Management and Processing

Farming with machineries brings manifold advantages like human drudgery reduction, increased efficiency, cost-effectiveness, shorter turn-around time, increased crop intensification, reduction of farm labor crisis, higher income, accelerated farm commercialization and many more. Ultimately, use of machine leads to higher productivity and contributes to farm growth. Innovative location specific irrigation system favors water and fertilizer efficiency facilitating reduction in production cost, and protects environment. Agro-processing has been recognized to be directly linked with employment generation, post-harvest loss redemption and ensuring fair price of farm produces followed by livelihood elevation. Realizing the importance of agricultural mechanization, research bound thematic area has been outlined in three important sub-sections to grasp full benefit as mentioned below.

Farm mechanization

The energy use in Bangladesh farm sector is relatively low indicating scope of further mechanization. Primarily, development and promotion of farmer's friendly machinery are needed to suit local farmers and improve efficiency of agricultural operations. New forms of machinery and equipment are essential for efficient use of renewable sources of energy. Efficient management of energy in agriculture for various operations is the key research and development challenge. High dependence on oil and non-renewable sources of energy may lead agriculture to more hazardous and less profitable by deteriorating nature. Novel sources of renewable energy need to be explored in order to protect environment and ensure cost effective production. However, the research focus may include the following:

- Development and fabrication of crop- and location-specific efficient machineries as a solution of labor shortage and an attraction of youth
- Innovation of climate smart conservation agriculture (CA) based machineries
- Transformation of agriculture aligning 4IR (IoT, AI, GIS, spatial software and sensor based agricultural technology)
- Efficient use of renewable energy (solar energy, biogas energy, etc.)

Irrigation and Water Management

Water is an extremely critical farm input essential for crop production. At the advent of global warming, the availability of this important input has become limited over the days. Similarly, the water-table is lowering sharply in most of the irrigated areas, for example in Barind areas (AEZ 26) and further water quality is deteriorating due to upward movement of salts and other pollutants. So, the challenge for research and development is to stop or minimize further degradation of water resources, increase

availability of fresh water resources and develop irrigation plan in a cost-effective manner. The key research issues relating to increased, safe and sustainable irrigation are outlined below.

- Mapping of total water (surface, groundwater and rainwater) availability for irrigation
- Development of region-specific efficient irrigation system
- Innovation of water-saving and automated climate smart irrigation technologies
- Efficient water management techniques using simulation modeling for major crops
- Renewable energy for irrigation

Postharvest Management and Processing

Agro-products marketing in Bangladesh is not properly organized and efficient and as high as 18 to 25% losses occur in the entire food supply-chain stretching from production to consumption. Markets of value-added and processed commodities are consistently increasing with increased consumer demands. Relatively low-cost and new dimensional technologies are required to unbridled potential and expand competitive market efficiency. To address limitations, particularly to reduce post-harvest losses, some well thought strategy like wrapping supply-chain by linking producers and markets, promoting processing of food commodities to add value before being marketed, developing small-scale processing refrigerated chambers or cold storages with conventional and non-conventional sources. But more focus should be paid in primary and secondary levels of value-addition and processing. Essentially these would necessitate multi-disciplinary and multi-stakeholder research in post-harvest engineering of farm produces.

- Postharvest loss minimization, nutrition sensitive fruit/vegetables processing and value addition, quality control and transportation
- Hazard analysis of fresh produce, processed food and food products in supply chain (producer, *paikar*, street vendor, traders, retailers, wholesalers etc.)
- Innovative smart postharvest machineries/technologies for processing and value addition
- Prototype development using big data analysis (artificial intelligence and machine learning algorithm) for identification and quantification of food adulterants and contaminants.
- Development of sensor based technology for assessing maturity indices of horticultural crops
- Small scale industrial processing of seasonal fruits like mango, pineapple, jackfruits, papaya etc. targeting export market.
- Innovative circular food systems including utilization of agro-wastes/food wastes.

Livestock Sub-sector

Animals are integral part of our culture and many farm families rely on livestock and poultry for their livelihood. These are unparalleled sources of premium quality, health promoting and life-saving proteins in the form of meat, milk and eggs. Besides direct products, a wide variety of processed foods are of animal origin, which widen scope for employment generation, and are also exported for bagging foreign currencies. Accordingly, concurrent research with competitiveness and competence in productivity, job creation, adroit natural resource management, safe and cost-effective food production systems and food security is highly desired. To make that happen the key important research issues of the sub-sector are listed below:

Thematic Area: Conservation, Improvement and Production of Animal Genetic Resources

It is vital to emphasize on local animal genetic resources (AnGR), which are thriving best under our hot and humid climatic condition. As an invaluable resource, AnGR should be collected, characterized and exploited for community development and sub-sectoral growth. Simultaneously, for increased production within short term, upgrading of local livestock and poultry with exotic breeds should be carried out very carefully up to a certain level. For better animal and poultry production, following research areas in animal breeding and genetics are focused:

- Collection, characterization, conservation and improvement of local breeds
- Evaluation of exotic breeds for their performance and exploitation
- Improvement of cattle, buffalo, goat, sheep and poultry production system
- Development of precision/vertical livestock farming system
- Improvement of Artificial Insemination (AI) and minimization of inbreeding depression
- Innovative animal management packages with good animal husbandry practices
- Development of low-cost waste management technique for livestock and poultry farms
- Improve reproductive performance (eg. Anestrous, repeat breeding etc.)
- Greenhouse gas emission and adequate mitigation

Thematic Area: Livestock Disease Management

Dry and sanitary surroundings are the key factors for disease prevention. Periodical vaccination, deworming and good feeding practices will facilitate preventing majority of diseases. Indigenous and traditional herbal product from plant origin may also be used as veterinary drug. Animal entering from abroad should be kept in strict quarantine to control trans-boundary disease movement. For safe animal raising, disease management plays a vital role, requiring much focused research as outlined below:

- Monitoring and surveillance of animal diseases including trans-boundary and zoonotic diseases

- Mapping of Antimicrobial Resistance (AMR) and development of adaptive mechanism against AMR
- Develop novel vaccines, biologics and therapeutics combating endemic and emerging diseases.
- Health hazard and remedial measures of drug toxicity, heavy metals and industrial wastes in the food chains of livestock origin
- Development of technology packages for modern bio-safety measures of animal farms

Thematic Area: Feeds and Fodder Production

Judicious and scientific utilization of agricultural and industrial by-products for animal and poultry feed are of prime importance. Therefore, due emphasis should be paid to research on indigenous and imported fodder varieties. Imported complete feed and feed ingredient should be checked for quality, especially for meat and bone meal. In the long run, hydroponics and aquaponics systems of fodder production need to be improved and adopted. Considering profound role of feed in animal and poultry performance, research should focus on the following issues:

- Collection, conservation and improvement of indigenous and exotic fodders
- Development of climate resilient high yielding forage/fodder variety
- Development of probiotics and prebiotics for better productivity
- Development of cost-effective feed for livestock and poultry
- Improvement of feed and fodder conservation and preservation technology
- Hygienic silage technology with home bound waste or other plant parts
- Location specific management practices for fodder production
- Fodder production by intercropping with leguminous crop
- Assessment and mitigation of nitrate/nitrite poisoning from young fodder
- Addressing toxins and heavy metals in livestock and poultry feed and products
- Formulation of innovative ration and Total Mixed Ration (TMR)

Thematic Area: Livestock and Poultry Product Processing and Value Chain

Processing of livestock products accompanied by value addition begets higher earnings and employs people. Besides the principal products, value added beef, poultry and dairy products processing enterprises are profit earning ventures which contribute to higher income. About 90% of livestock products are produced by smallholder poor village farmers, which necessitate ensured marketing. However, dairy products like cheese and yoghurt are also therapeutic in nature. Under these backdrop, research focus should be directed in the following line:

- Development of techniques for production of safe and functional value-added meat, milk, and egg products
- Development of marketing structure, marketing system and value chains for meat, milk and poultry products

- Supply chain, value chain and marketing of farm produces
- Appropriate probiotics for value addition
- Monitoring and surveillance of imported livestock products and byproducts with special reference of milk powder

Fisheries Sub-sector

A rice cum fish bowl is not only a traditional meal and also a part of our culture whereas fishes are the most abundant and commonly taken proteins. Naturally grown fishes were plenty in the past but due to various human interventions, climate change, netted hitches, habitat destruction and pollution, over fishing, siltation etc. have contributed hugely to eroding the invaluable resources. In the context of increasing population, demand for diversified safe food, climate difficulties, job opportunity and livelihood improvement etc., the existing research is inadequate. As such, an update research vision is crucial to meet the anticipated demand of the sub-sector. Under these perspectives, the following fisheries specific thematic area has been recognized as focus issues for research:

Thematic Area: Enhancement of Fish Productivity and Production

Current fish production technologies and management tools have provided the foundation for further innovation in fish production, resource management, and economic development. However, continual improvements are needed for further increase in productivity through the enhancement of production systems and improvement of technologies, which could be achieved through attending the following sub-thematic areas.

Production system

The need for practices to increase fish production avoiding or minimizing harm to the environment resonates in fisheries production systems. Current production systems are not always well managed, and much more fish could be produced by simply improving management practices, regardless of the scale of aquaculture operations. Successful fish production system depends on creation of optimal conditions for adaptability, growth and reproduction, properly matching species to appropriate production environments, nutrient availability and recycling, and healthy ecosystems that facilitate disease free cultures species. As such, the important research could be:

- Eco-friendly intensified inland open water aquaculture
- Resource efficient indoor and outdoor closed water intensive aquaculture
- Integrated and nutrient sensitive aquaculture system
- Climate smart aquaculture in coastal, char and haor ecosystems
- Species diversification in aquaculture
- Mechanization and application of IoT (Internet of Things) in fish production management

Fish feed and feeding management

In aquaculture production system, feed is the most vital input that constitutes major share (60-70%) of recurring cost. While fishmeal replacement by complementary protein sources is required to address the high cost of fish feed, it is imperative to find nutritionally balanced low-cost and low-environment degrading aqua feeds with alternative feed additives. It is also important for judicious use of these aqua feeds with proper feeding strategy to improve immunity/health and consequently the growth performance and survival of aquaculture species. In this regard, the important research areas are:

- Alternative sources of fish diet ingredients and additives to replace animal proteins
- Cost- and nutrition-efficient fish feed formulation
- Feeding strategy for ontogenic stages of cultured fish and shellfish species
- Precision nutrition for optimal fish production performance
- Molecular nutrition and epigenetic mechanisms of fish growth

Fish health management

Intensification of fish farming inevitably leads to increased prevalence of fish diseases and environmental contamination, hindering the sustainability of aquaculture. Diseases and epizootics are considered to be major bottlenecks for increasing production of fishes for sectorial development. In general, diseases have caused serious economic losses to fin and shellfish aquaculture. Disease control is becoming a challenging task as the resources for prevention are very meagre or limited. The important research areas are:

- Use of biotechnology and nanotechnology related tools and techniques for early disease diagnosis, management and resistance
- Epidemiology of emerging pathogens causing fish and shellfish disease outbreak
- Novel fish disease surveillance and diagnostics tools with a focus to bio-security
- Area based management (ABM) approaches for fish health management
- Bio-prosperity of indigenous plants and microbes in fish disease prevention
- Development of rapid disease test kits and vaccines
- Assessment of disease resistance traits and varieties

Thematic Area: Fisheries Protection, Conservation and Management

In addition to the challenges posed by climate change, capture fisheries in Bangladesh are threatened by overexploitation due to poor management and habitat degradation. To mitigate these challenges, one of the country's research and development priorities in capture fisheries development is to improve conservation and management of both inland and marine fisheries resources and restore threatened and degraded fisheries habitats through efficient science-based actions. Effective conservation supported by sound evidence including research and action in line with conservation and

management rules and policies would complement one another. In these connection, the possible important research areas are outlined below:

- Characterization and understanding of fisheries habitat change over time
- Identification of key aquatic areas for ecosystem improvement of fish biodiversity
- Novel techniques (e.g. eDNA) to restore degraded fish habitat and biodiversity
- Novel genetic tools and analyses for fish stock structure and assessment
- Improvement of fish sanctuary, stocking, etc. for conservation of fish biodiversity
- Hilsa resources management
- Detection and mitigation of emerging contaminants in aquatic systems
- Nature-based solutions for point and nonpoint source of pollution

Fish genetics and improvement

To maintain the stake of genetic diversity on its natural aquatic wealth and potential benefits, the challenge lies with collection, characterization and conservation of fish germplasm in association with development of repositories of genetic resources. Genetic improvement of production traits has a great potential to help meeting the rising aquaculture industry. There is a soaring demand for the selection of traits with efficient digestibility, nutrient profile, other consumer-appealing product characteristics, and disease resistance. However, the challenge of producing selectively bred fish species that do not present a threat to existing wild populations as invasive or polluting genetic material will become increasingly acute. Considering the perspectives, the research issues are advocated as:

Fish germplasm collection, characterization and conservation

- Characterization of genetic stocks/races in wild populations
- Real time working model of *ex-situ* conservation
- Novel tools and methods for zoning and managing *in-situ* conservation

Fish breeding

- Domestication, artificial breeding and mass seed production
- Use of biotechnology and nanotechnology tools for reproductive success
- Innovative hatchery systems for fish and freshwater prawn

Genetic improvement

- Integration of advanced genetic tools into selective breeding
- Balancing between selective breeding and biosecurity
- Genetic basis of different fish traits by applying genomic tools
- High-throughput genotyping of major commercial aquaculture species
- Development of genetic markers for fish genetic/population improvement
- Production of genetically all male and/or female for suitable species
- Transgenic fish considering environmental risk and food safety.

Thematic Area: Fish harvesting, Post-harvest, Processing and Value addition

High post-harvest losses are a matter of great concern in the fishing industry. Research efforts are needed for post-harvest loss reduction, responsible fishing, fish quality, shelf-life expansion, product development and value addition. Reduction of food loss and waste is especially pertinent to improve fish value chains in Bangladesh, where people rely on aquatic resources for food and income. However, there are challenges to develop real-life methodologies that accurately measure the magnitude and sources of post-harvest losses in capture fisheries and aquaculture. The challenges are also immense as how to promote the use of methodologies by key institutions within target fisheries, develop and promote appropriate value addition and loss reduction processes and technologies applicable to major stakeholder groups. The important research areas are outlined as below:

Fish harvesting

- Improvement of traditional fishing systems
- Integration of machinery and IT for fish stock tracking and harvesting
- Cost-effective and innovative fishing gears using catch reduction devices

Post-harvest, processing and value addition

- Innovations to reduce post-harvest loss of fish and waste in the fish value chains
- Need-based and species-specific fish processing and value-addition
- Ready to cook fish products development, processing and preservation
- Utilization of fish wastes, by-catch, low value fish, etc.
- IT-based monitoring systems for traceability
- Rapid estimation methods for universally accredited quality control
- Use of nanotechnology in value-added fish and fishery products
- Innovation and promotion of products and by-products processing

Thematic area: Blue Economy

Despite the country's abundant marine resources, the full fisheries and aquaculture potential of the Bay of Bengal is yet to harness in the context of increasing need for food and resources from the marine sources meeting the demand of the growing population. Among the key challenges for the promotion of the blue economy, conservation and environmental protection towards economic growth, social development, collection of data and information following analytical methodologies on a range of different sustainability dimensions are of particular concern for the future. In these regard, the following research areas are important:

- Management and restoration of coastal wetlands and shorelines
- Exploration of potentials for new fishing grounds and marine fisheries
- Maximum exploitation of fish stocks from all depths to ensure healthy ecosystems

- Site selection for marine aquaculture of fish, shellfish, seaweeds etc.
- Domestication, breeding and culture of potential marine fish and shellfish species
- Use of pharmaceutical products and chemicals for marine living resources
- Development of cost-effective ways to prevent illegal, unregulated and unreported (IUU) fishing in marine ecosystems
- Next-generation sequencing technologies in assessing fisheries stock structure
- Improving the efficiency of fishing gear and vessels through digital innovations

Cross Cutting Issues

There is a good number of research agenda which are common but very crucial in the sub-sectors. The sub-sectors of agriculture are interrelated in terms of functions and interactions, which requires addressing some cross-cutting issues for better performance of all the sub-sectors. The following research areas should be taken into consideration as a whole:

Thematic Area: Technology Validation and Adoption

Effective delivery mechanism of a technology is imperative in minimizing wide gap between potential and realized productivity. In spite of significant advancement in the technology generation, there is still moderate to low adoption of modern production technologies due to lack of appropriate adoption framework at place. Given the rapid rate of technological obsolescence in most cases, the ability to accurately forecast demand for user acceptable technologies and services is essential for end-users. Therefore, innovative and appropriate working models and practices need to be developed for effective adoption of location specific agricultural technologies along with their wider dissemination.

The far-reaching, participatory information and communication technologies are to be developed continually by optimizing print and electronic delivery systems and by showcasing research products in various forms for effectively linking research innovations with the stakeholders. There are three concerned areas as key research issues to observe an effective delivery system of farm technologies as mentioned:

Technology validation

- Improvement of technology hubs as validation and dissemination platforms
- Participatory and innovative approach of technology generation and validation

Technology delivery system and assessment

- Evaluation of current extension tools and improvement of methods for technology uptake
- Novel approaches for dissemination of water efficient technologies
- Effective approach for reducing adoption lag

- Development and introduction of innovative digital technologies and tools for wider scale dissemination
- Promotion of e-extension, patenting, GAP and commercialization of farm technologies
- Improvement of public-private partnership in dissemination system

Linkage improvement

- Development of public-private partnership for technology diffusion and entrepreneurship development.
- Innovative methods for linkage development among researchers, extension workers, producers, manufactures, traders etc.

Thematic Area: Farming Systems

In farming systems research the whole farm is viewed as a system. Therefore, research is conducted with recognition and emphasis on the choice of priorities that reflect the whole farm. It aims for maximizing the economic and biological performance of enterprises ensuring sustainability, including the rehabilitation and regeneration of natural resource systems. It includes off-farm and non-farm activities that make up sustainable livelihoods. The following research areas are considered for increasing productivity and improving nutrition and livelihood status of the small holders.

- Integrated farming system involving agricultural diversification, intensification and value addition
- Innovation and replication of agro-forestry models
- Development of family farming models for nutrition, income and better livelihood
- Designing and evaluation of vertical farming
- Development of crop based organic farming and the related cultural practices
- Innovation and replication of promising hill, *gher*, urban and peri-urban farming
- Verification and development of crop zone based productivity
- Development of Zone Based Farming (Crop, livestock and fisheries) to manage pests and diseases and promotion of export
- Development and adoption of agro-ecological approaches for farming

Thematic Area: Socio-economic Issues and Marketing

In recent years, the need for socio-economic information has increased greatly due to the effects of extended sectoral jurisdiction, growth in awareness of resource constraints, increased interest in nutrition, socioeconomic issues including safe and humane working conditions, etc. It is also imperative that sustainability of agro-food production cannot be achieved without adequate attention to intra and inter-linkage from production to consumer sector in a chain of various systems involved in marketing. The pertinent research issues include:

- Mapping of climate impacts on farm growth for taking corrective measures

- Assessment of socio-economic and technological determinants in adoption
- Appropriate agricultural transformation system for small-holder farmers
- Generation of employment opportunity and retention of women and youth in farming
- Socio-economic aspects of innovated technologies and perception
- Pro-poor cooperative farming and agri-business framework model
- Circular economy in farming
- Improvement of value chain and marketing channels
- Pro-poor and pro-gender socio-economic analysis in crops, fisheries and livestock
- Market analysis and promotion of safe agro-products
- Development of cost-effective e-marketing
- Promotion of market intelligence and marketing for home and abroad facilitating commercial agriculture
- Innovation and promotion of agribusiness and viable rural industrial clusters

Thematic area: Climate Change

Climate change has consequences not only to biological responses, but also direct and indirect implications to farm operations. This phenomenon is expected to accelerate over decades, resulting in dire economic consequences, extreme food insecurity, and threatens livelihood. Rigorous research on climate change impacts on farm productivity and livelihood and its mitigation and adaptation combining local, national and regional actions are required to generate new knowledge and practices. Under this respect, the research areas are considered pertinent:

- Climate linked stressors to ecology, biology and farming operations
- Climate change adaptation and mitigation strategies to develop climate-smart technologies for sustainable farming and environment
- Community-based resilience to climate change in agriculture
- Adaptation actions in agricultural sub-sectors including management of soil and water resources, forestry, livestock coastal and marine resources
- Search for potential crops, fisheries, livestock species and fodder varieties adaptive to climate change impacts
- Ecosystem habitat preservation of plants, livestock and fisheries
- Widely integrated water management, early warning systems, irrigation improvement, and demand-side management

Thematic Area: Policy Issues

Government regulations are needed for the execution of policy issues at field level. There should be an enabling public policy intervention favoring execution of research vision to harness the potentials of science and novel technologies. In the area of policy issue, the following areas can be considered:

- Periodical population and food demand projection for revising priority research

- Policy research to promote technology dissemination, value chain and marketing
- Establish legal and conducive environment to promote and encourage public private partnership in R & D
- Policy research on market intelligence and marketing facilitating commercial agriculture
- Improvement of efficiency of human resources and effective utilization of infrastructure
- Innovation and promotion of agribusiness and viable rural industrial clusters
- Commercialization of technologies through organized intellectual property rights and benefit sharing system.

STRATEGIES AND FRAMEWORK

Bangladesh has been transforming from a food deficit to a food self-sufficient country. Among several factors, agricultural policy reforms and technological innovations have contributed to achieving food self-sufficiency of the country. Nevertheless, this is a big concern as how to meet food demand of increasing population when the country's natural resource base is shrinking and degrading. Besides, the country possesses fragile ecosystems (called hot spots) which are vulnerable due to climate change effects. Then, the future food security depends on how efficiently and effectively the ecologically challenged areas (haors, charlands, barind, coastal and hills covering 0.87, 0.92, 2.78, 1.06 and 1.81 M ha, respectively) are brought under agricultural production. It is anticipated that about 35% food production should be increased by 2041 and so innovative strategies are needed to sustain food security and combat hunger (Bokhtiar *et al.*, 2023).

It is also important to note that demand for high-value commodities is increasing rapidly with the rising per capita income and growing urbanization. To meet the demand of these commodities, research focus should be further strengthened to augment their production more efficiently and competitively. Thus, demand-driven research strategies and government policies, and their implementation could be the best instruments for improved and sustained productivity by ensuring food nutrition and safety of agricultural produces. Hence, appropriate strategies need to be formulated to improve agricultural productivity, nutritious and safe food production, value addition and food processing, easy access to genetic materials and knowledge resources. It also requires effective climate and market risk management, smart integrated farming systems, soil and water quality development, robust technology delivery system, human resources development, commercialization of technologies to address the emerging challenges. The possible approaches against each objective are stated below.

Objective 1: Improve agricultural productivity

It is an enormous challenge to meet the food demand of increasing population under decreasing arable land accompanied with soil degradation and climate vulnerability. Scope exists to address this challenge by giving emphasis on agricultural intensification, development of demand-driven high yield potential varieties (livestock, poultry & fish) and judicious management of natural resources. Another opportunity exists to explore Blue Economy through sustainable use of ocean and sea resources. In the marine ecosystems, there remains potential opportunities for development of marine aquaculture as a part of blue economy development in Bangladesh (Aftabuddin *et al.*, 2021). However, there are some challenges that need to be addressed to improve mariculture and contribute to a growing blue economy in Bangladesh. To achieve improved productivity in farm sector following approaches could be adopted.

- Promote agricultural intensification and diversification

- Development of varieties/breeds to address climate change induced biotic and abiotic stresses
- Production of quality seed and planting material for reducing yield and adoption gap
- Improvement of marine aquaculture towards the development of Blue Economy
- Synergy of crop-livestock-fish-agroforestry-horticulture by harnessing increased productivity, developing sustainable production systems and innovating pollution mitigation technologies
- Blue economy, as almost a huge unexplored area, needs to be exploited in all dimension

Objective 2: Enhance nutrient rich and safe food production

Bangladesh has been paying a special emphasis on both intensification and diversification through the National Agriculture Policy 2018 on all aspects of safe food and nutrition. Despite significant progress in food security and poverty reduction, about 35% of Bangladesh's population remains undernutrition, with around 10% of women reported as moderately or severely undernourished (NIPORT, 2013). Malnutrition is exacerbated by poor diversity, with 70% of the diet comprising cereals, and inadequate protein and micronutrient intake (Magnani *et al.*, 2015). Introduction of high yield potential micronutrient bio-fortified rice varieties contributes to a nutritionally improved diet. Hence, considering the present food security situation, attention is now needed to address the problems regarding food nutrition and safety. The following strategies could be an important consideration in achieving this objective.

- Sustainable agricultural diversification with emphasis on high value and low volume crops.
- Innovative solutions to mitigate problems related to food nutrition, food safety and value added agro-products processing.
- Development of safe food, nutrient rich and therapeutic farm products (crops, livestock and fisheries) considering long-term sustainability issues

Objective 3: Improve harvesting, value addition and food processing

Post-harvest loss of crop produce occurs to the extent of 5-35% over the entire food supply-chain from production to consumption. Higher post-harvest loss arises from fruits (mango, jackfruit, pineapple, litchi, guava, banana etc.) and vegetables (tomato, brinjal, cauliflower, cabbage, beans, peas etc.), which have poor shelf life. Opportunity exists to reduce post-harvest loss by improving post-harvest handling and storage. Value addition through integrated value chains and market intelligence could be priority research. To that end, the following strategies are suggested:

- Development of technologies to minimize post-harvest losses in the field, storage and transportation

- Enhancing shelf-life of fruits, vegetables, milk, meat and fishes
- Improvement of post-harvest processing, preservation and value addition of food commodities.

Objective 4: Improve access to genetic material, information and knowledge resources

Access to genetic materials, information and knowledge resources can bring a good impact on increasing food production. The NARS institutes have a variety of genetic resources of crops, animals and fishes. In this regard, the Information and Communication Technology (ICT) could perform a great role in improving access to genetic material and knowledge resources toward exploitation of germplasm. In achieving the said objective, the following strategies are important.

- Germplasm exploration and maintenance (*in-situ* and *ex-situ)*
- Improve access to information through effective use of ICT
- Access to geospatial data and knowledge resources

Objective 5: Improve risk management

Risk management refers to climate, market and bio-risk management. Bangladesh is under high risk from the impact of climate change. Being a low-lying river delta with a long coastline and floodplains that occupy 80% of the country, it faces extreme vulnerability to the adverse effects of climate change (BDP 2100, 2018). Pest and diseases accounting bio-risk threatens farm production. Fortunately, Bangladesh has a number of national strategies and plans that address risk management and adaptation. Apart from climate risk, market risk management is also important. Market risk arises due to changes in interest rates, exchange rates, geopolitical events, market price of agricultural produce etc. The possible strategies to meet this objective could be as follows:

- Development of technologies and management approaches for climate change adaptation and mitigation including early warning system
- Addressing market risks through improved market intelligence and improved market access
- Technological innovations for bio-risk management

Objective 6: Smart integrated farming systems

Integrated Farming System (IFS) is potential to achieve food and nutrition security at household level. It is prospective in fulfilling the increasing demand for nutritious food, stable farm income and improved livelihood with limited resources by optimizing resource utilization. Integration of different agricultural enterprises provides the ways to recycle products and by-products of one component as input of other linked component which reduces the production cost and raises total farm income. This objective could be addressed by adopting the following strategies:

- Integration of different agricultural enterprises (crops, livestock and fisheries) to ensure cost effective production and higher income
- Innovation of integrated farming systems, vertical farming etc., models for food and nutrition security
- Agricultural waste management, biogas and biofuels generation and composting to facilitate safe agricultural production
- Facilitation of green/renewable energy in farm sector and low-cost feed development
- Innovate and encourage bio-risk intelligent system

Objective 7: Improve and maintain the quality of natural resources

With the increasing agricultural productivity, pressure on soil and water resources are increasing, so its effective and rational use could be a core strategy to sustain the productivity. There is a dire need to conserve soil, land and water resources, so that short-term exploitative measures on natural resources do not jeopardize long-term soil productivity. Hence, to improve and maintain the quality of natural resources the following strategies could be undertaken.

- Management options to improve soil and marginal land quality
- Development of technological options to enhance water use efficiency, water quality and water availability
- Innovations to improve air quality by reducing greenhouse gas emissions (CO_2, CH_4 & N_2O)
- Upholding Conservation Agriculture having economic, yield and environmental benefits

Objective 8: Robust technology delivery system

It is important to continuously strive to develop viable and high profit bearing technologies. Simultaneously, technologies developed have to be assessed at farm level with greater participation of farmers and be fine-tuned to suit the local needs. To bridge the gap between the technologies developed at research stations and its adoption by farmers, the technology validation, refinement and dissemination should be strengthened. The possible strategies to achieve this objective could be as follows:

- Establishment of networking of agricultural research and extension machineries with forward and backward linkages
- Development of technology delivery systems using mass communication tools
- Research on remote sensing, AI, IoT, Robotics, Cloud computing and Big data management towards more-informed production business and operational decisions

Objective 9: Human resources development (HRD) to address emerging challenges

Skilled and efficient human resources are a prerequisite for novel technological innovations and agricultural education. Maintaining global standards and enhancing competitiveness are also important in agri-business and technology development. Vertical integration of agricultural education is the key to improve quality of human resources. HRD includes various opportunities such as scientists' higher education and training in various fields such as integrated farming systems, climate resilient innovations, precision agriculture, food safety management, molecular techniques, biotechnology, GIS, modeling, research planning and management etc. The strategies towards HRD could include the following aspects:

- Strengthening scientists' capacity through higher studies and training
- Development of a futuristic human resource development program
- Enhancement of competitive capacity of the HR through talent management
- Development of a performance-based work-culture with incentives and rewards system
- Strengthening NARS institutes by reducing shortage of skilled scientists
- Exploring international and regional partners in HRD and capacity development

Objective 10: Commercialization of agricultural technologies

After achieving food security followed by nutritious and safe food, the future thrust shall be paid to promote commercial agriculture which is conducive for a vibrant and profitable farm sector. Commercialization of agricultural technologies is needed for the benefit of farmers as well as society. As the distances and differences between countries become narrower through emerging technologies, the need for a global patent system becomes imperative. More far-reaching and far-sighted viable approaches and strategies under this objective are suggested as outlined below:

- Development of intellectual property rights and benefit sharing system
- Strengthening technology management system
- Export bound zone based production system
- Strengthening the linkage of Academia-Researcher-Extension personnel-Producer-Trader-Consumer
- Promote effective, efficient and decentralized governance by introducing best management practices in public and private sector research systems and development

WAY FORWARD

Bangladesh began its voyage as a food (rice) deficit country, but that outrageous situation has been reverted down by country's toiling farmers supported by the Government policies and supports. Efforts with expansion of modern rice varieties, irrigation expansion and use of agrochemicals, termed as Green Revolution enabled the country to produce enough food to meet the rapidly growing demands but accelerated biodiversity loss and environmental pollution. Under declining share in GDP, the sector will play a key role in ensuring food security and nutrition balance, and to achieve these inter-sectoral policies have to be directed towards a highly productive, diversified and climate-resilient innovations.

As a result of rapid transformation in the sector, the country is self-sufficient in rice, fruits, fish, meat and egg production and but lag behind in vegetable self-sufficiency (Bokhtiar *et. al.,* 2022) and milk (www.dofl.gov.bd). Despite remarkable progress accomplished, the country is importing most of its required pulses and oilseeds, claiming huge foreign reserve. All these glitches are expected to be relapsed into possibilities through scientific and policy interventions. Given that view Bangladesh Agricultural Research Vision 2041 has been framed in concurrence with related policy documents. The vision document emphasized that cutting-edge climate resilient technology development endeavors together with viable natural resources management will receive a momentum if it is intelligently and precisely followed for productivity growth, safe and nutrition rich farm sector.

The progress of the sector is expected to be surged if science-led technology based diversified farming, cost-effectiveness, input efficiency, environmental protection, safe food production, agro-processing, value chain, export bound production, mass employment, capacity development etc. are ensured. The progress is further expedited if ultimately a profit earning farm enterprises is embarked. Thus, a science-led and demand driven innovations and adaptation of climate smart technologies associated with bio-fortification and gene editing as a major concern of scientists and policy makers to ensure an efficient safe and profitable production system towards commercial farming is projected. This requires implementation of strategies of the vision document after reverting innumerable defies. The sector shall be attaining a sturdy ground if efficiency and intellectual capacity of all concerned are appropriately integrated with smart usage of natural resources. Some important action plans have been proposed below to fulfil the strategic objectives.

- A time bound action plan to be prepared and executed addressing the outlined research areas and strategies
- Deployment of appropriate and sufficient human resources, budget and resource allocation for enhancing the capacity of NARS institutes and allied public organizations involved in agricultural research, and promote performance-based work culture

- Strengthening collaboration and linkage among research organizations, universities and extension agencies for undertaking research, technology validation and adoption
- Initiative of inter-ministerial coordination for promoting market intelligence and marketing for home and abroad facilitating commercial agriculture
- Establishment of legal and conducive environment to promote and encourage public private partnership in research and development
- Strengthening collaboration and cooperation with international and regional research organizations and development partners to materialize the research vision abstracted
- Innovation and promotion of effective, efficient and decentralized governance by introducing best management practices in public and private sector research system
- Strong governance ensuring accountability, transparency, participation and structural strategies for addressing climate change, economy and livelihood.

All these measures as proposed will facilitate accomplishment of building life-long waited dream Sonar Bangla of the Father of the Nation Bangabandhu Sheikh Mujibur Rahman and Smart Bangladesh by 2041.

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