Songklanakarin J. Sci. Technol.
35 (3), 261-274, May - Jun. 2013

SJST SONGKLANAKARIN JOURNAL OF SCIENCE AND TECHNOLOGY
http://www.sjst.psu.ac.th

Review Article

Wheat and rice, the epicenter of food security in Bangladesh

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Received 4 April 2012; Accepted 18 April 2013

Abstract

Agriculture is the prime economic activity in Bangladesh, but global warming is expected to severely reduce the yield of various crops, including wheat and rice, directly affecting the food security of 165 million people. Even though Bangladesh has achieved significant progress in agriculture, especially with respect to rice production and yield, the demand for rice still outstrips domestic production, and the country remains a net importer of rice. With an expanding population, planning for future cereal production and demand is crucial to meeting Bangladesh's food security challenges. To facilitate this planning, projections of future supply and demand for cereals are critical. This study is an attempt at carrying out such future projections with a view to assessing the likely gap between supply and demand. This information will also help to mould a global perspective plan of rice and wheat research in Bangladesh to meet the food demand of an increasing population for years to come.

Keywords: food security, wheat, rice, future global warming

1. Projections of world rice and wheat production, demand and closing stocks

Food security is based on production, demand and the effectiveness of the market. The OECD-FAO (2011) stated that world wheat production is projected to reach 746 Mt by 2020, about 11% higher than in the base period 2008-2010, but with slower annual growth relative to the previous decade (Table 1). The expansion of the production area is projected to be modest, 2% higher than the base period by 2020 with the largest expansions projected for the Russian Federation, Ukraine and Kazakhstan. Average global yield growth for wheat is projected at only 0.8%, reflecting strong historical yield growth in major producing countries (OECD-FAO, 2011; Table 1).

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In 2020, world rice production is projected to be 528 Mt, approximately 67 Mt higher than the base period (OECD-FAO, 2011; Table 1). The annual growth rate is forecast at 1.3%, significantly slower than 2.2% in the previous decade. Yield growth (1.1%) is the main driver behind the global increase in production, as little change in total rice area is expected. Developing countries are expected to account for virtually all of the projected increase in production, particularly India, Cambodia, Myanmar and African countries (IndexMundi, 2013). Among large producers, China is expected to cut output by 7 Mt as the sector responds to declining domestic consumption and strong competition for land (OECD-FAO, 2011; IFPRI, 2012; Table 1).

Wheat is expected to remain a commodity predominantly consumed for food, roughly 68% of total use by 2020, slightly below its current share (OECD-FAO, 2011; Table 1). Per capita food consumption is projected to remain around 66 kg per person (FAO, 2010). World wheat feed utilization is expected to reach 145 Mt by 2020, growing at a slightly

Table 1. Projections of world's rice, wheat and coarse grains' production, demand, closing stocks and price from 1998 to 2021 (Sources: OECD-FAO, 2011; FAO, 2010; IFPRI, 2012; IndexMundi, 2013)

Parameters	Units	Year of projections										
		Avg. 08/09-10/11est	11/12	12/13	13/14	14/15	15/16	16/17	17/18	18/19	19/20	20/21
Wheat												
Production	Mt	674.0	677.4	684.9	694.2	706.3	711.9	719.4	724.9	732.1	739.3	745.9
Area	Mha	223.2	223.6	223.2	223.8	225.3	225.1	226.0	226.3	226.7	227.3	227.6
Yield	t/ha	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2	3.2	3.3	3.3
Consumption	Mt	660.0	679.0	687.4	691.9	702.3	709.7	718.4	725.7	732.5	739.2	745.7
Feed use	Mt	126.2	132.3	134.2	133.7	137.1	137.0	138.9	140.6	142.2	143.3	145.1
Food use	Mt	454.2	463.4	468.8	472.4	477.7	483.5	489.1	494.0	499.0	503.9	508.5
Closing stocks	Mt	195.3	191.5	189.2	191.7	196.0	198.5	199.8	199.3	199.1	199.4	199.9
Price	USD/t	264.5	278.6	234.1	247.9	237.6	240.7	238.8	241.8	241.3	241.2	240.4
Rice												
Production	Mt	460.8	472.5	477.1	483.6	490.4	496.2	502.9	509.1	515.2	521.7	528.1
Area	Mha	159.5	160.8	160.8	161.0	161.4	161.7	162.0	162.2	162.3	162.5	162.7
Yield	t/ha	2.9	2.9	3.0	3.0	3.0	3.1	3.1	3.1	3.2	3.2	3.2
Consumption	Mt	452.9	469.7	476.5	483.0	489.8	496.4	503.5	510.1	516.4	522.8	528.9
Feed use	Mt	13.5	13.8	14.0	14.1	14.3	14.3	14.6	14.6	14.9	15.0	15.2
Food use	Mt	387.5	400.3	406.9	413.3	419.9	426.4	433.2	440.0	446.6	453.4	460.0
Closing stocks	Mt	133.5	141.4	141.6	142.0	142.3	141.9	141.0	139.7	138.3	137.0	135.9
Price	USD/t	599.7	538.7	503.6	478.2	472.4	472.5	474.0	478.5	482.9	488.6	492.5
Coarse grains												
Production	Mt	1121.6	1167.9	1191.7	1213.4	1222.1	1241.1	1246.7	1270.7	1285.2	1310.3	1320.7
Area	Mha	325.9	331.7	334.6	337.1	337.3	340.0	340.1	342.6	343.9	346.4	347.3
Yield	t/ha	3.4	3.5	3.6	3.6	3.6	3.7	3.7	3.7	3.7	3.8	3.8
Consumption	Mt	1113.0	1160.1	1181.4	1200.8	1212.8	1228.1	1245.0	1264.2	1280.3	1298.4	1313.2
Feed use	Mt	627.2	640.9	651.1	660.0	666.5	677.2	689.0	699.6	709.3	719.8	728.7
Food use	Mt	197.2	206.9	209.3	212.7	215.6	219.3	222.5	225.8	228.9	232.3	235.5
Closing stocks	Mt	211.1	189.5	193.7	200.1	203.3	210.1	205.6	206.1	204.8	210.5	211.9
Price	USD/t	197.9	229.0	202.5	202.3	206.4	204.9	207.2	207.2	207.9	205.3	202.8

slower pace than in the historical period, though still representing around 19.5% of total use (OECD-FAO, 2011; Table 1).

Rice is consumed mainly as food, with about 14% accounting for feed or post-harvest losses. World overall rice utilization is set to reach 529 Mt in 2020, up from a 2008-2010 average of 453 Mt (OECD-FAO, 2011; Table 1). The projected annual utilization growth rate is 1.3%, slightly below the past decade (1.5%). Per capita food consumption of rice is set to increase at a rate of 0.5% reaching 60 kg per person in 2020. Rice consumption in Africa is anticipated to rise rapidly amid relatively strong population expansion and a continued shift in diets towards rice (IndexMundi, 2013). The opposite is expected in China, where slow population growth, steady income growth and urbanization may depress total rice consumption by 0.3% (FAO, 2010; OECD-FAO, 2011).

Wheat stocks are set to recover from the low levels in 2010 and slightly increase over the projection period under normal weather conditions (200 Mt in 2020) (OECD-FAO, 2011; Table 1). Most of the buildup is expected in CIS and in the Near East, offsetting declines in the US and EU (FAO, 2010; OECD-FAO, 2011; IndexMundi, 2013). Inventories in China are projected to remain below 60 Mt. At this level, the ratio of world wheat stocks-to-use will approach 27% in 2020, slightly below the base period, but three percentage points above 2007, when the world faced the last major food crisis (OECD-FAO, 2011; Table 1). Similarly, the ratio of major exporters' wheat stocks-to-disappearance is projected at 16% in 2020 (Table 1).

World rice inventories have been increasing strongly since 2008, boosted by strong production and by a few governments move to increase public rice reserves (FAO, 2010; IndexMundi, 2013). Stock accumulation is expected to slow, reaching 136 Mt by 2020 (Table 1). This downward trend is mainly driven by China and India (IndexMundi, 2013). The rice stocks-to-use and stocks-to-disappearance ratios are projected to decrease to 26% and 13%, respectively by 2020 (OECD-FAO, 2011; Table 1).

2. Rice and wheat research and production in Bangladesh: securing food production and beating climate change

Bangladesh is primarily an agrarian economy with a high population density, where food security remains a major concern. The agriculture sector alone contributes about 12% of GDP and employs 44% of Bangladesh's workforce (IUCN, 2010; IFPRI, 2012), which could greatly assist in improving the food security of hunger-prone Bangladeshi, at least 35% of which suffer from malnourishment (Lal *et al.*, 2001; IFPRI, 2012).

The major food items in Bangladesh are rice, wheat, pulses, potato, vegetables and fish, which contribute almost 85% of the total calorie and protein intake (Begum and Luc D'Haese, 2010). Rice and wheat alone contribute 71 and 53% of the total per capita calorie and protein intake, respectively (BBS, 2008). It is projected that up to 2021 in Bangladesh, the annual demand for food will exceed supply, 0.28% for rice and 1.76% for wheat, implying that demand is greater than supply for both crops (Begum and Luc D'Haese, 2010).

Rice is the staple food of about 165 million people of Bangladesh (IndexMundi, 2013; Table 2). It provides nearly 48% of rural employment, about two-thirds of total calorie supply and about one-half of the total protein intake of an average person in the country; the rice sector contributes one-half of the agricultural GDP and one-sixth of the national income; almost all of the registered 13 million farm families grow rice on about 10.5 million ha which has remained almost stable over the past three decades (BRKB, 2012).

Total rice production in Bangladesh was about 10.59 million tons in 1971 when the country's population was only about 70.88 million. However, Bangladesh now produces about 34.0 million tons to feed 164 million people (IndexMundi, 2013; Table 2). This indicates that the growth of rice production was much faster than population growth. This increase in rice production was possible largely due to the adoption of modern rice varieties on around 66% of land dedicated to rice, contributing about 73% of the country's total rice production (BRRI, 2013). However, there is no reason to be complacent. The population of Bangladesh is still growing by two million every year and is expected to increase by another 30 million over the next 20 years. Thus, Bangladesh will require about 27.26 million tons of rice for 2020. During this time total rice area also is expected to shrink to 10.28 million ha. Rice yield therefore, needs to be increased from the present 2.74 to 3.74 t/ha (BRKB, 2012).

Wheat is not a traditional grain crop of Bangladesh and was not always an integral part of Bangladeshi food security. Currently wheat occupies about 4% of the total cropped area and 11% of the area cropped in *rabi* (winter cropping season from November to February), and contributes 7% to the total output of food cereals (BBS, 2008; Table 2). Wheat production peaked in the early 2000's through the use of high-yielding varieties, slumped during the economic crisis of 2006-2009 and has slowly regained its production and domestic consumption values (BBS, 2012; Hossain and Teixeira da Silva, 2013; IndexMundi, 2013; Table 2).

In recent years (the period from 2010 to 2012), Bangladesh's agriculture sector has averaged an annual growth of around 3% (average growth rate of rice and wheat), on par with, if not more than, some of its South Asian neighbors (World Bank 2009; BRRI, 2013, IndexMundi, 2013; Table 2). The structural makeup of the agricultural sector in Bangladesh points toward the importance of the cereal sector. The share of cereals in the total value of agricultural output in the triennium ending 2008 was 53%, showing only a slight decline from its share of 55% in the triennium ending 1998 (FAO, 2010).

Among cereals, the primary position is occupied by rice. In fact, with almost 75% of the total cropped area under rice cultivation, it could be said that rice is the primary crop for Bangladesh's entire agricultural sector (Table 2, 3; IFPRI, 2012). In comparison, wheat and maize—the other two cereals having some presence in Bangladesh—are relatively minor crops. Rice production has shown a steady increase in Bangladesh and has even shown signs of acceleration in growth in recent years (Table 2, 3). In particular, the growth rate in rice yields has gone up. In the last five years (from 2008 to 2012), the average annual growth rate in yield of rice had reached 3.32%, as compared with the previous five years (2.82%) (Table 2). On the other hand, wheat in Bangladesh has been on a downward trend. From about 0.88 million hectares (ha) (1.9 million tons) in 1999, wheat area and production had fallen to fewer than 0.4 million ha and less than 0.85 million tons, respectively, by 2009 (IFPRI, 2012; Table 2). Bangladesh remains a net importer of rice despite significant progress in improving yield and production levels (Table 2, 3, 4). With a growing population, planning for future cereal production to meet food security challenges would require projections of future supply and demand for cereals (IndexMundi, 2013, BRRI, 2013).

In June 2012, the International Food Policy Research Institute published a report to provide forecasts of the demand and supply of cereals in Bangladesh for the period 2015-2030, focusing on rice as the main staple in Bangladeshi diets and also the most important crop in Bangladesh's agriculture (IFPRI, 2012). A detailed model of the supply of rice in the three main rice-growing seasons—Aman, Aus, and Boro—was built up through separate acreage and yield functions, which were estimated with data from the Bangladesh Bureau of Statistics. Supply and demand projections were made for the years 2015, 2020, 2025, and 2030 under various scenarios. Under alternative conditions that captured land availability constraints facing rice cultivation in Bangladesh, rice supply in 2015 is expected to be in the range of 31.2 to 35.2 million tons, and it is likely to grow to 39 million tons by 2030 (IFPRI, 2012). Household direct demand projections are made under three scenarios on the growth of real per capita income— 4.2%, 3.6%, and 3.0%. Assuming constant prices,

Table 2. Area, production, domestic consumption and import of rice and wheat for increasing population in Bangladesh (Sources: BBS, 2012; BRRI, 2013; IFPRI, 2012; Hossain and Texeira da Silva, 2013; IndexMundi, 2013)

Year	Population (millions)	Production (1000 MT)		Domestic consumption (1000 MT)		Total Cropped area (million ha)	Area (1000 ha)		Imported (1000 MT)	
		Wheat	Rice	Wheat	Rice		Wheat	Rice	Wheat	Rice
1970-71	-	112 *(0%)	9932 *(0%)	1183	10613	-	126	9257	1071	681
1971-72	-	115 (3%)	10090 (1.6%)	2511	10418	-	110	9629	2396	384
1972-73	-	111 (-3%)	11909 (18.0%)	1670	11950	-	105	9878	1559	81
1973-74	-	116 (5%)	11287 (-5.2%)	2110	11571	-	105	9793	1994	262
1974-75	-	218 (88%)	12762 (13.1%)	1250	12839	-	169	10329	1032	390
1975-76	-	259 (19%)	11753 (-7.9%)	872	12266	-	180	9882	613	193
1976-77	-	348 (34%)	12969 (10.4%)	1698	13060	-	212	10028	1679	305
1977-78	-	494 (42%)	12849 (-0.9%)	2770	13157	-	265	10114	2054	60
1978-79	-	836 (69%)	12740 (-0.9%)	2531	13242	-	433	10064	2055	720
1979-80	90.40	1093 (31%)	13882 (9.0%)	1997	13590	-	591	10309	993	84
1980-81	92.85	967 (-12%)	13631 (-1.8%)	2357	14113	13.16	534	10459	1111	144
1981-82	95.35	1095 (13%)	14216 (4.29%)	2546	14571	13.20	519	10587	1500	317
1982-83	97.89	1210 (11%)	14500 (2.0%)	2702	14890	13.00	530	10546	1876	180
1983-84	100.44	1464 (21%)	14620 (0.8%)	3530	14925	13.36	676	10140	1898	690
1984-85	102.99	1042 (-29%)	15040 (2.9%)	2125	15201	13.15	540	10403	1164	39
1985-86	105.54	1091 (5%)	15406 (2.4%)	2815	15789	13.54	585	10609	1614	261
1986-87	108.08	1091 (0%)	15413 (0.1%)	2923	15800	13.34	585	10322	1873	691
1987-88	110.60	1020 (-7%)	15550 (0.9%)	3204	15897	13.82	560	10220	2207	120
1988-89	113.12	890 (-13%)	17860 (14.9%)	2316	17674	13.71	592	10478	1179	324
1989-90	115.63	1004 (13%)	17852 (-0.1%)	2221	18153	14.06	599	10435	1399	11
1990-91	118.13	1004 (0%)	18250 (2.2%)	2551	18138	14.03	599	10240	1457	39
1991-92	120.61	1065 (6%)	18340 (0.5%)	2138	18586	13.18	575	10160	1051	10
1992-93	123.09	1176 (10%)	18041 (-1.6%)	2241	18300	13.70	637	9980	1065	100
1993-94	125.58	1131 (-4%)	16833 (-6.7%)	2738	18267	13.48	615	9922	1707	1300
1994-95	128.09	1245 (10%)	17687 (5.1%)	2558	18366	13.52	639	9941	1243	1140
1995-96	130.61	1370 (10%)	18882 (6.8%)	2257	19139	13.51	701	10414	957	46
1996-97	133.15	1454 (6%)	18862 (-0.1%)	2489	20062	13.80	708	10263	839	1200
1997-98	135.69	1803 (24%)	19854 (5.3%)	3839	21854	14.09	805	9689	2032	2500
1998-99	138.24	1988 (10%)	23066 (16.2%)	3412	23766	13.96	805	10708	1624	400
1999-00	140.77	1673 (-16%)	25086 (8.8%)	2866	24958	14.27	773	10887	1293	672
2000-01	143.29	1610 (-4%)	24310 (-3.1%)	2950	25553	14.30	750	10666	1565	243
2001-02	145.80	1510 (-6%)	25187 (3.6%)	3000	26100	14.30	707	10777	1335	955
2002-03	148.28	1253 (-17%)	26152 (3.8%)	3050	26700	14.17	567	10902	1945	850
2003-04	150.73	976 (-22%)	25600 (-2.1%)	3000	26900	14.23	556	11000	2058	725
2004-05	153.12	820 (-16%)	28758 (12.3%)	2950	29000	14.10	480	11100	2034	514
2005-06	155.46	740 (-10%)	29000 (0.8%)	2800	29764	14.20	372	11200	1731	769
2006-07	157.75	1200 (62%)	28800 (-0.7%)	2800	30747	14.20	440	11100	1500	2047
2007-08	160	849 (-29%)	31000 (8.3%)	3300	31000	16.50	400	11100	2882	602
2008-09	162.22	850 (0%)	31000 (-0.6%)	3700	31600	13.88	400	11600	3331	92
2009-10	164.43	972 (14.3%)	33200 (2.3%)	4100	34000	13.91	374	11700	3900	1560
2010-11	165.00	1000 (2.9%)	33700 (6.3%)	4100	34300	-	400	11720	2800	563
2011-12	-	1100 (10%)	33800 (0.3%)	4200	34500	-	420	11650	3000	250

* Figure in the parenthesis indicate % growth rate as compare to previous year

per capita household demand for the year 2030 for rice are projected to be in the range of 183.7 to 192.3 kilograms (kg) per capita per year (IFPRI, 2012). The corresponding forecasts for wheat are in the range of 6.5 to 7.1 kg per capita per year in 2030. Combining these with alternative population forecasts from the government of Bangladesh and the

Table 3. Trend of rice production (1000 MT) in Bangladesh according to year and rice seasons (Aus, Aman and Boro): MV- Modern variety; LV- Local variety. (Sources: BBS, 2012; BRRI, 2013)

Year	Aus (1000 MT)				Aman (1000 MT)				Boro (1000 MT)				MV%
	MV	LV	Total	%MV	MV	LV	Total	%MV	MV	LV	Total	%MV	
1971-72	129	2212	2341	5.51	696	4999	5695	12.22	966	772	1738	55.58	18.32
1972-73	137	2106	2243	6.11	980	4607	5587	17.54	1340	731	2071	64.70	24.82
1973-74	381	2420	2801	13.60	1957	4742	6699	29.21	1611	609	2220	72.57	33.69
1974-75	695	2164	2859	24.31	1071	4929	6000	17.85	1629	621	2250	72.40	30.59
1975-76	857	2372	3229	26.54	1208	5837	7045	17.15	1633	653	2286	71.43	29.44
1976-77	825	2189	3014	27.37	897	6008	6905	12.99	1299	351	1650	78.73	26.11
1977-78	904	2199	3103	29.13	1145	6277	7422	15.43	1602	637	2239	71.55	28.60
1978-79	961	2326	3287	29.24	1494	5935	7429	20.11	1511	418	1929	78.33	31.36
1979-80	830	1979	2809	29.55	1708	5595	7303	23.39	1882	545	2427	77.54	35.25
1980-81	1075	2214	3289	32.68	2061	5903	7964	25.88	1990	640	2630	75.67	36.92
1981-82	1022	2248	3270	31.25	1667	5542	7209	23.12	2515	637	3152	79.79	38.18
1982-83	936	2129	3065	30.54	2075	5441	7516	27.61	3033	515	3548	85.48	42.78
1983-84	1007	2215	3222	31.25	2049	5794	7843	26.13	28.32	518	3350	84.54	40.85
1984-85	862	1921	2783	30.97	2200	5730	7930	27.74	3348	561	3909	85.65	43.84
1985-86	922	1906	2828	32.60	2438	6104	8542	28.54	3219	452	3671	87.69	43.74
1986-87	967	2163	3130	30.89	2525	5742	8267	30.54	3580	430	4010	89.28	45.90
1987-88	891	2102	2993	29.77	2450	5240	7690	31.86	4294	437	4731	90.76	49.53
1988-89	729	2127	2856	25.53	2582	4275	6857	37.65	5422	409	5831	92.99	56.18
1989-90	609	1866	2475	24.61	3856	5346	9202	41.90	5672	361	6033	94.02	57.24
1990-91	631	1630	2261	27.91	4246	4921	9167	46.32	5950	407	6357	93.60	60.88
1991-92	770	1409	2179	35.34	4656	4613	9269	50.23	6370	437	6807	93.58	64.62
1992-93	711	1364	2075	34.27	5088	4592	9680	52.56	6236	350	6586	94.69	65.62
1993-94	719	1130	1850	38.88	4951	4468	9419	52.56	6419	353	6772	94.78	67.01
1994-95	702	1088	1790	39.21	4483	4021	8504	52.72	6201	338	6539	94.83	67.64
1995-96	702	974	1676	41.89	4681	4109	8790	53.25	6852	369	7221	94.89	69.17
1996-97	843	1027	1870	45.08	5359	4192	9551	56.11	7105	355	7460	95.24	70.48
1997-98	872	1003	1874	46.49	5206	3644	8849	58.83	7796	342	8137	95.80	73.55
1998-99	728	889	1617	45.02	4741	2995	7735	61.28	10152	399	10552	96.22	78.48
1999-00	798	936	1734	46.02	6246	4060	10306	60.61	10671	356	11027	96.77	76.80
2000-01	935	981	1916	48.80	6938	4311	11249	61.68	11553	367	11920	96.92	77.44
2001-02	903	905	1808	49.94	6810	3916	10729	63.49	11412	354	11766	96.66	78.70
2002-03	947	903	1850	51.19	7144	3974	11118	64.25	11873	349	12222	97.14	79.25
2003-04	936	895	1831	51.10	7529	3991	11521	65.36	12432	404	12837	96.85	79.80
2004-05	862	638	1500	57.47	6693	3126	9819	68.16	13446	390	13837	97.18	83.48
2005-06	1081	664	1745	61.95	7505	3305	10810	69.43	13628	347	13975	97.52	83.73
2006-07	996	516	1512	65.87	7867	2974	10841	72.57	15709	256	14965	98.29	86.29
2007-08	1099	408	1507	72.93	7715	1947	9662	79.85	17536	226	17762	98.73	91.08
2008-09	1448	447	1895	76.41	9075	2538	11613	78.15	17589	218	17809	98.76	89.77
2009-10	1316	393	1709	77.00	9403	2804	12207	77.03	17845	214	18059	98.81	89.33
2010-11	1739	394	2133	81.55	10142	2650	12792	79.28	18514	102	18616	99.45	90.62

United Nations Department of Economic and Social Affairs, the total direct demand for rice in 2030 is projected to be in the range of 31.3 to 42.0 million tons, up from 26.8 to 29.2 million tons in 2015. For wheat, the projection for 2030 is 1.1 million to 1.5 million tons. Adding indirect demand requirements to this, the total demand for rice in 2030 is expected to be in the range of 34.8 million and 52.5 million tons (IFPRI, 2012).

3. Global warming: impact on rice and wheat production, the agriculture sector and food security in Bangladesh

The prospect of global warming resulting from accumulation of greenhouse gasses is causing major concern, especially in relation to its potential effect on rice production (Wassmann *et al.*, 2009b). While the rise in CO_2 concentration would be expected to have a beneficial effect, the overall results will be negative in the tropics, where most of the world's poor live. Rising sea level will reclaim some of the rice lands in coastal regions, increase salinity intrusion, and impede drainage leading to more flooding problems in low-lying areas, like Bangladesh (Mackill *et al.*, 2010). Increasing frequencies of both drought and floods will result from more erratic rainfall and extreme weather events. Higher temperatures will also have a negative effect on rice production. High temperature can affect rice growth and development at all stages, and particularly if it occurs during pollination (Mackill *et al.*, 2010).

Similarly, wheat production is also sensitive to temperature: it requires low temperature at certain stages to obtain a desirable yield and temperature fluctuations in wheat-growing areas is worsening the ability to produce this crop (Hossain *et al.*, 2009; Hossain and Teixeira da Silva, 2012; Hossain *et al.*, 2011; 2012a, b; Hakim *et al.*, 2012; Hossain and Teixeira da Silva, 2013).

Agriculture is always vulnerable to unfavorable weather events and climate conditions. Despite technological advances such as improved crop varieties and irrigation systems, weather and climate are still key factors in agriculture productivity (BRRI, 2013). Often the link between these key factors and production losses are obvious, but sometimes the links are less direct. The impacts of climate change on food production are global concerns, and they are very important for Bangladesh. Agriculture is the largest sector of Bangladesh's economy, which accounts for about 35% of the GDP and about 70% of the labor force (Basak, 2009; Basak *et al.*, 2009, 2010). Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems related to the depletion of agricultural land and water resources (Ahmed *et al.*, 2000). Bangladesh needs to increase the rice yield in order to meet the growing demand for food emanating from population growth. Irrigated rice or Boro rice is a potential area for increasing rice yield, which currently accounts for about 50% of total rice production in the country (BRRI, 2006; Basak *et al.*, 2010). However, climate change is a potential threat toward attaining this objective. It is therefore very important to understand the effect of climate change on rice production, especially Boro production (Basak, 2009; Basak *et al.*, 2009, 2010).

Rimi *et al.* (2009) studied a recent trend of climate change and prediction of future climate change scenarios with Global Climate Models (GCMs) and most importantly investigated the impacts of climate change on rice production. In the case of future climate change prediction, GFDL-TR (Geophysical Fluid Dynamics Laboratory Transient) predicted delta values ranging from 1.1 to 1.7°C for 2050, while it varied from 1.5 to 2.3°C for 2070. In contrast, the UKTR (UK Meteorological Office/Hadley Centre Transient with respect to the base year of 1990) suggested a mean temperature increase of 1.5 to 2.1°C in 2050 and 1.2 to 2.7°C in 2070 (Rimi *et al.*, 2009). According to HadCM2 (Hadley Centre during 1995 and 1996 using the Second Version of the United Kingdom Meteorology Office's Unified Model)-generated delta values, temperature would increase 1.3 to 2.9°C in 2050 and 1.7 to 4.0°C in 2070. It is evident that different GCMs predicted different sets of values for temperature increase (or decrease). Among the three GCMs, GFDL-TR predicted milder changes while HadCM2 suggested severe changes and the values increased with time. In the case of rainfall, GFDL-TR and UKTR both predicted a decreasing tendency in the future during winter (DJF) (Rimi *et al.*, 2009). However, HadCM2 suggested that there would be higher precipitation (35.6% increase in 2050 and 48.9% increase in 2070) during DJF, which would benefit agriculture. Different crops responded differently under different climate change scenarios. Yield of Boro was reduced from 3.47 to 48.64% in calcareous soils but increased from 0.16 to 16.47% in non-calcareous soil (Rimi *et al.*, 2009). In T. Aman, increased yields (up to 49%) could be observed under rainfed conditions in future climate change scenarios. However, there was also a declining trend of yields ranging from 1 to 12%. The most detrimental effects were observed in T. Aus. The yield decreased in all soil conditions and future climate scenarios. The per cent yield difference decreased from at least 5% up to 42%. In most cases, irrespective of crops and GCMs, climate change would have a negative impact (Rimi *et al.*, 2009).

Sarker *et al.* (2012) examined the relationship between the yield of three major rice crops (Aus, Aman and Boro) and three main climate variables (e.g., maximum temperature, minimum temperature and rainfall) for Bangladesh. They used time series data for the 1972–2009 period at an aggregate level to assess the relationship between climate variables and rice yield using both the ordinary least squares and median (quantile) regression methods. The findings of their study confirmed that climate variables have had significant effects on rice yields but that these effects vary among three rice crops. Maximum temperature is statistically significant for all rice yields with positive effects on Aus and Aman rice and with adverse effects on Boro rice. Minimum temperature had a statistically significant negative effect on Aman rice and a significantly positive effect on Boro rice. Finally, rainfall had a statistically significant effect on Aus and Aman rice. Nonetheless, the influences of maximum temperature and minimum temperature were more pronounced compared with that of rainfall. Given these effects of temperature on rice crops and increasing climate change vulnerabilities, policy makers should fund research and the development of temperature-tolerant rice varieties, particularly for Aman and Boro rice (Sarker *et al.*, 2012).

Sarker *et al.* (2013) assessed the impacts of climate variables on the mean and variability in Aus variety rice yield in Bangladesh. Using the theoretical framework of the Just–Pope production function, cross-sectional time series data on Aus rice yield and maximum temperature, minimum temperature and rainfall at a district level over a period of 38 years were analysed for evidence of rice yield variability as a result of climate change. The findings revealed that minimum temperature and rainfall decreased Aus yield variability. However, maximum temperature appears to increase variability, which may reduce Aus rice production (Sarker *et al.*, 2013).

During the last 50 years, Bangladesh suffered about 20 drought episodes, with four major droughts occurring in the last 25 years, mostly in northwestern Bangladesh (Selvaraju *et al.*, 2006; IUCN, 2010). During 1981 and 1982, droughts affected the production of monsoon crops only. Drought in north-western Bangladesh led to a shortfall in rice production of 3.5 million tons in the 1990s (IUCN 2010). More recently, the droughts of 1994-95 in the northwestern districts of Bangladesh led to a 3.5 million tones shortfall of rice and wheat production while the 1997 drought loss of approx. 1 million tones of food grain, of which about 0.6 million tonnes was transplanted Aman rice valued at around US$500 million (Selvaraju *et al.*, 2006). If losses to other crops (including wheat) are considered, the loss will be substantially much higher (Banglapedia, 2010). Every year Bangladesh experiences a dry period for 7 months, from November to May, when rainfall is normally low. During this period about 2.7 million ha of land in Bangladesh are vulnerable to annual drought and, according to the Government of Bangladesh, there is about a 10% probability that 41-50% of the country would experience drought in any given year (Tanner et al., 2007).

The Intergovernmental Panel on Climate Change (IPCC, 2007) estimates that by 2050, there will be changing rainfall patterns with increasing temperatures, flooding, droughts and salinity that would impact Aus rice production, causing a decline in Bangladesh by 8% and in wheat by 32%, *versus* 1990 as the base year (CCC, 2009). Recent estimates using different models with changed assumptions predicted, for 2050, a reduction in production by 1.5-25.8% for Aus rice, and by 0.4-5.3% for Aman rice due to higher temperatures (Habibullah *et al.*, 1998).

More detail of wheat production in Bangladesh has been outlined in a recent review (Hossain and Teixeira da Silva, 2013).

4. Stress tolerant rice and wheat varieties for adaptation to a changing climate

Rising temperatures due to the accumulation of greenhouse gasses are expected to result in declining rice yields in the tropics. In addition to the direct effect of high temperature in reducing yields, a rise in sea level coupled with more erratic and extreme weather events will result in reduced yields and increase the risks of rice farming (Mackill *et al.*, 2006; Mackill *et al.*, 2010). The abiotic stresses that are anticipated to worsen as the consequences of climate change include high temperature, drought, flooding and salinity stresses. Although flooding is not of major importance or consequence to the wheat crop at present, some perspectives are provided on this stress since wheat is flood-sensitive and the incidence of flooding is likely to increase (Hossain and Teixeira da Silva, 2013). While high temperature is not currently a major problem, the other stresses are already widespread yield-limiting factors in the unfavorable environments of tropical Asia. Incorporating stress tolerance into high-yielding varieties has proven to be a very effective approach to developing varieties that can cope with these situations. These successes provide optimism that the problem of climate change can be addressed partially through development and dissemination of adapted germplasm (Mackill *et al.*, 2006, 2010).

These damaging effects can be effectively addressed through plant breeding. Rice breeding has been a very successful activity in the past few decades, particularly in favorable areas. During the 1970s, modern, high-yielding varieties (HYVs) were rapidly adopted in irrigated and favorable rainfed lowland areas (Mackill *et al.*, 2006, 2010; BRRI, 2013). However, these varieties were not ideal for more unfavorable areas in which poor water control and adverse soil conditions limited yields, and most farmers in these areas continued to grow low-yielding varieties. Breeding for tolerance to abiotic stresses was rapidly expanded during this time. The HYVs have continued to spread throughout both irrigated and rainfed areas and now cover the majority of the production areas in tropical Asia. However, these varieties are invariably intolerant to the current major abiotic stresses that are likely to be further aggravated by climate change, such as drought, submergence, and salinity. These stresses reduce yields in millions of hectares in rice production areas; and modern HYVs have had limited impact in these areas (Mackill *et al.*, 2006, 2010).

Without a doubt, traditional plant breeding and agriculture will be the prime means of sustainably securing rice and wheat as the two top staple crops in Bangladesh. To this end, researchers of Bangladesh institutions under the National Agricultural Research Systems (NARS) are engaged in innovative technologies that will be resilient to ensure expected crop production. Research and development of stress (salt, submergence, drought, high temperature)-tolerant rice and wheat varieties can ensure food security by an increase in yield of up to 20% (IUCN, 2010). The Bangladesh Rice Research Institute (BRRI) has released salt-tolerant rice varieties such 'BR-11', 'BR-23', 'BRRI rice-28', 'BRRI rice-41', 'BRRI rice-47', and 'BRRI rice-53' and 'BRRI rice-54' using gene-marker technology (MoEF, 2010; BRRI, 2013). Seeds of var. 'BRRI rice-47' are multiplied by the Bangladesh Agricultural Development Corporation (BADC) and disseminated by the Department of Agriculture Extension (DAE) to farmers for cultivation in salinity-prone southern districts. Short duration varieties such as 'BR-33' by BRRI and 'BINA-7' are cultivated by the Bangladesh Institute of Nuclear Agriculture (BINA) to avert the so-called *monga* situation in northern Bangladesh. 'BRRI rice -32' and 'BRRI rice-52' can stand submergence during flash floods (MoEF, 2010; BRRI, 2013). Moreover, BADC is testing the adaptability of an African rice variety, 'NERICA-1', which is drought tolerant (Okeleye *et al.*, 2013). The Bangladesh Agriculture Research Institute (BARI) is working with heat-tolerant wheat varieties (Hossain and Teixeira da Silva, 2013).

For future climate change forecasting and food demand for the increasing population of Bangladesh, BRRI has been developing high-yielding modern varieties (MVs) of rice and has so far released 61 MVs (57 inbred lines and 4 hybrids) (Table 4). With appropriate management, and under favorable soil and environmental conditions, these MVs may yield 5-7 t/ha in the Boro, 3-4 t/ha in the Aus, and 4-5 t/ha in the transplant Aman seasons compared with no more than 2-3 t/ha by traditional varieties (BRRI, 2013; Tables 3, 4, 5). A few of BRRI's MVs are now widely grown in a few other countries, including India, Nepal, Bhutan, Myanmar, Vietnam and West Africa. During the early years of research, BRRI followed IRRI in developing semi-dwarf photoperiod-insensitive varieties (BRRI, 2013). Over time, BRRI scientists

Table 4. Trend the yield of modern and local varieties according to year and seasons (Aus, Aman and Boro): MV- Modern variety; LV- Local variety. (Source: BRRI, 2013)

Year	Aus (t ha^{-1})			Aman (t ha^{-1})			Boro (t ha^{-1})		
	MV	LV	Total	MV	LV	Total	MV	LV	Total
1971-72	2.63	0.75	3.38	2.75	0.97	3.72	3.00	1.42	4.42
1972-73	2.06	0.74	2.80	1.76	0.89	2.65	3.04	1.30	4.34
1973-74	1.36	0.81	2.17	2.37	0.97	3.34	2.74	0.96	3.70
1974-75	2.46	0.75	3.21	2.14	1.00	3.14	2.47	1.24	3.71
1975-76	2.43	0.77	3.20	2.17	1.12	3.29	2.54	1.29	3.83
1976-77	2.26	0.77	3.03	2.13	1.12	3.25	2.40	1.12	3.52
1977-78	2.28	0.80	3.08	2.29	1.19	3.48	2.50	1.41	3.91
1978-79	2.26	0.83	3.09	2.18	1.16	3.34	2.26	1.03	3.29
1979-80	2.06	0.75	2.81	1.96	1.10	3.06	2.60	1.28	3.88
1980-81	2.21	0.84	3.05	2.14	1.16	3.30	2.67	1.55	4.22
1981-82	2.17	0.84	3.01	1.75	1.10	2.85	2.80	1.57	4.37
1982-83	1.97	0.79	2.76	1.93	1.11	3.04	2.81	1.46	4.27
1983-84	2.01	0.84	2.85	1.93	1.17	3.10	2.66	1.55	4.21
1984-85	1.85	0.78	2.63	2.04	1.24	3.28	2.72	1.63	4.35
1985-86	1.91	0.81	2.72	2.07	1.26	3.33	2.65	1.41	4.06
1986-87	1.78	0.92	2.70	2.02	1.20	3.22	2.67	1.38	4.05
1987-88	1.79	0.92	2.71	2.05	1.19	3.24	2.62	1.44	4.06
1988-89	1.75	0.94	2.69	1.91	1.14	3.05	2.57	1.33	3.90
1989-90	1.73	0.98	2.71	2.19	1.36	3.55	2.63	1.20	3.83
1990-91	1.73	0.94	2.67	2.16	1.29	3.45	2.63	1.44	4.07
1991-92	1.86	0.94	2.80	2.21	1.29	3.50	2.73	1.45	4.18
1992-93	1.91	1.01	2.92	2.18	1.31	3.49	2.65	1.41	4.06
1993-94	1.79	0.91	2.70	2.18	1.27	3.45	2.75	1.44	4.19
1994-95	1.69	0.87	2.56	2.09	1.17	3.26	2.57	1.33	3.90
1995-96	1.68	0.87	2.55	2.06	1.22	3.28	2.73	1.50	4.23
1996-97	1.77	0.92	2.69	2.17	1.26	3.43	2.85	1.23	4.08
1997-98	1.78	0.93	2.71	2.04	1.12	3.16	2.92	1.57	4.49
1998-99	1.65	0.90	2.55	1.92	1.11	3.03	3.09	1.62	4.71
1999-00	1.82	1.03	2.85	2.26	1.38	3.64	3.11	1.57	4.68
2000-01	2.00	1.14	3.14	2.48	1.48	3.96	3.24	1.82	5.06
2001-02	2.01	1.14	3.15	2.38	1.41	3.79	3.20	1.75	4.95
2002-03	2.03	1.16	3.19	2.43	1.45	3.88	3.24	1.96	5.20
2003-04	1.25	1.98	3.23	2.52	1.48	4.00	3.33	1.94	5.27
2004-05	1.91	1.11	3.02	2.30	1.32	3.62	3.47	2.08	5.55
2005-06	2.09	1.28	3.37	2.35	1.48	3.83	3.50	1.99	5.49
2006-07	2.07	1.21	3.28	2.36	1.43	3.79	3.58	1.88	5.46
2007-08	1.96	1.14	3.10	2.27	1.18	3.45	3.91	1.80	5.71
2008-09	2.10	1.20	3.30	2.45	1.41	3.86	3.83	1.78	5.61
2009-10	2.03	1.17	3.20	2.49	1.48	3.97	3.88	2.00	5.88
2010-11	2.18	1.25	3.43	2.60	1.52	4.12	3.92	2.04	5.96

Table 5. BRRI released 61 MVs (57 inbred and 4 hybrid) from 1970 to 2012: 14 for Boro, 8 for Aus, 27 for Aman, 1 for Boro and Aus and 1 for Boro, Aus and Aman (Source: BRRI, 2013)

Rice variety	Growing season	Plant height (cm)	Size, shape and colour	Growth duration (days)	Average yield (t/ha)	Year released
BR1 (Chandina)	Aus	88	Short bold	120	4.0	1970
	Boro	88		150	5.5	
BR2 (Mala)	Aus	120	Medium slender white	125	4.0	1971
	Boro	120		160	5.0	
BR3 (Biplob)	Aus	100	Medium bold	130	4.0	1973
	Aman	100		145	4.0	
	Boro	95		170	6.5	
BR4 (Brrisail)	Aman	125	Medium bold white	145	5.0	1975
BR5 (Dulabhog)	Aman	120	Short bold aromatic	150	3.0	1976
BR6	Aus	113	Long slender white	110	3.5	1977
	Boro	100		140	4.5	
BR7 (BRRI Balam)	Aus	125	Long slender	125	3.5	1977
	Boro	125		155	4.5	
BR8 (Asha)	Aus	125	Medium bold	125	5.0	1978
	Boro	125		160	6.0	
BR9 (Sufala)	Aus	125	Long medium bold white	120	5.0	1978
	Boro	125		155	6.0	
BR10 (Progati)	Aman	115	Medium slender	150	5.5	1980
BR11 (Mukta)	Aman	115	Medium bold	145	5.5	1980
BR12 (Moyna)	Aus	105	Medium bold white	130	4.5	1983
	Boro	105		170	5.5	
BR14 (Gazi)	Aus	120	Medium bold white	120	5.0	1983
	Boro	120		160	6.0	
BR15 (Mohini)	Aus	100	Medium slender white	125	5.0	1983
	Boro	90		165	5.5	
BR16 (Shahiblam)	Aus	110	Long slender white	130	5.0	1983
	Boro	90		165	6.0	
BR17 (Hashi)	Boro (for haor area only)	125	Medium slender	155	6.0	1985
BR18 (Shahjalal)	Boro (for haor area only)	115	Medium bold white	170	6.0	1985
BR19 (Mongol)	Boro (for haor area only)	110	Medium bold	170	6.0	1985
BR20 (Nizami)	Aus	120	Medium bold	115	3.5	1986
BR21 (Niamot)	Aus	100	Medium bold	110	3.0	1986
BR22 (Kiron)	Aman	125	Short bold white	150	5.0	1988
BR23 (Dishari)	Aman	120	Long slender white	150	5.5	1988
BR24 (Rahmat)	Aus	105	Long slender white	105	3.5	1992
BR25 (Nayapajam)	Aman	138	Short bold white	135	4.5	1992
BR26 (Srabani)	Aus	115	Long slender white	115	4.0	1993
BRRI dhan27	Aus	140	Medium bold	115	4.0	1994
BRRI dhan28	Boro	90	Medium slender white	140	6.0	1994
BRRI dhan29	Boro	95	Medium slender white	160	7.5	1994
BRRI dhan30	Aman	120	Medium slender white	145	5.0	1994
BRRI dhan31	Aman	115	Medium bold white	140	5.0	1994
BRRI dhan32	Aman	120	Medium bold white	130	5.0	1994
BRRI dhan33	Aman	100	Short bold	118	4.5	1997
BRRI dhan34	Aman	117	Short bold aromatic	135	3.5	1997
BRRI dhan35	Boro	105	Short bold	155	5.0	1998
BRRI dhan36	Boro	90	Long slender	140	5.0	1998
BRRI dhan37	Aman	125	Medium slender aromatic	140	3.5	1998
BRRI dhan38	Aman	125	Long slender aromatic	140	3.5	1998
BRRI dhan39	Aman	106	Long slender	122	4.5	1999
BRRI hybrid dhan1	Boro	110	Medium slender white	155	8.5	2001
BRRI dhan40	Aman	110	Medium slender	145	4.5	2003
BRRI dhan41	Aman	115	Long bold	148	4.5	2003
BRRI dhan42	Aus	100	Medium white	100	3.5	2004
BRRI dhan43	Aus	100	Medium bold white	100	3.5	2004

Table 5. Continued

Rice variety	Growing season	Plant height (cm)	Size, shape and colour	Growth duration (days)	Average yield (t/ha)	Year released
BRRI dhan44	Aman	130	Bold	145	5.5	2005
BRRI dhan45	Boro	100	Medium bold white	145	6.5	2005
BRRI dhan46	Aman	105	Medium bold	124	4.7	2007
BRRI dhan47	Boro	105	Medium bold	152	6.0	2007
BRRI dhan48	Aus	105	Medium bold	110	5.5	2008
BRRI dhan49	Aman	100	Medium slender	135	5.5	2008
BRRI hybrid dhan2	Boro	105	Medium bold	145	8.0	2008
BRRI dhan50 (Banglamoti)	Boro	82	Long slender aromatic white	155	6.0	2008
BRRI hybrid dhan3	Boro	110	Medium bold	145	9.0	2009
BRRI dhan51	Aman	90	Medium slender white	142/154	4.5	2010
BRRI dhan52	Aman	116	Medium bold	145/155	5.0/4.5	2010
BRRI hybrid dhan4	Aman	112	Medium slender white	118	6.5	2010
BRRI dhan53	Aman	105	Medium slender	125	4.5	2010
BRRI dhan54	Aman	115	Medium slender	135	4.5	2010
BRRI dhan55	Boro	100	Long slender	145	7.0	2011
	Aus	100		105	5.0	
BRRI dhan56	T.Aman	115	Long bold	110	5.0	2011
BRRI dhan57	T.Aman	115	Long slender	105	4.5	2011
BRRI dhan58	Boro	100	Medium slender white	155	7.5	2012

deviated from the IRRI concept of dwarfism for high yield, and restructured the IR8 plant type to suit local agro-ecological and climatic conditions with intermediate plant height having relatively longer growth cycles and mild photo-period sensitivity (BRRI, 2013).

Very recently, eight varieties, two of which are aromatic, have been developed. These are awaiting final evaluation by the National Seed Board for release as new cultivars. About 8,000 germplasms, most of which are local, have been collected and preserved in the BRRI gene bank. BRRI is now moving ahead with a radical idea of developing a new rice plant type with 'cluster grains' panicles which are expected to bring about a 20-25% yield improvement over the existing MVs (BRRI, 2013; Table 5).

On the other hand, as a result of intensive research and breeding efforts, the yield potential and yield quality of 10 existing wheat varieties of Bangladesh have improved (compared to old varieties; see Table 6) and most of them are tolerant to stress (Hossain and Teixeira da Silva, 2012; Hossain *et al.*, 2012a; Hossain and Teixeira da Silva, 2013; BARI, 2013; Tables 6, 7).

5. Conclusions

Bangladesh is an agrarian economy with a high population density. Modelling projections for Bangladesh indicate that climate change is likely to have an adverse impact on the production of wheat and rice. This is not only due to the direct effect of higher temperatures, but also due to problems associated with extreme weather events such as drought, submergence and salinity, and a rise in sea-level (Wassmann *et al.*, 2009a). These problems will be especially acute in the coastal and delta regions, where flooding and salinity are likely to increase (Ismail *et al.*, 2010). However, these exact conditions have existed for centuries in the coastal regions of Asia like Bangladesh, India and Thailand, where rice production provides the main livelihood and nourishment of the populations.

With an expanding population, planning for future cereal production and demand is crucial to meeting the food security challenges in Bangladesh. To facilitate this planning, projections of future supply and demand for cereals are critical. This study is an attempt at carrying out such future projections with a view to assessing the likely gap between supply and demand. This information will also help to make global perspective plans for rice and wheat research in Bangladesh to meet the food demand of increasing population.

Acknowledgements

We thank to Dr. P.K. Malaker, Chief Scientific Officer, and Dr. M.A.Z. Sarker, Principal Scientific Officer, Wheat Research Centre, Bangladesh for their encouragement, suggestions and information that have allowed us to include more precise information within this review.

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Table 6. Characteristics of wheat varieties of Bangladesh developed since 1974 to 1993 (Sources: BARI, 2013; CIMMYT, 2013).

Variety	Synonym	Genes	Yield (t ha^{-1})	Sowing time	Harvest time	Year of release
Kalyansona/ Mexi Pak	-	Lr1; lr2a/b/c/d; Lr3(do)/(ba); Lr3; Lr9; Lr10; Lr11; Lr12; Lr13; Lr14a/b; Lr15; Lr16; Lr17; Lr18; Lr19; Lr20; Lr21; Lr22+; Lr22b; Lr22; Sr2; Sr6; Sr9; Sr10; Sr11; Sr17; Yr1; Yr2; Bt4; Ne1; Ne2; Rht1; Rht-B1b; Rht-D1a; D1; D2; D3/D3; Vrn1; Vrn2; Vrn3; Gai1; Kr1; Kr2; Rg1; Apd1; Apd2; Nor-B1a; Nor-B2b; Est-A5b	2.6-3.6	Nov.15-30	Mar.-Apr.	1974
Sonora 64	-	Lr1; Lr2a; Lr2c; Lr3; Lr23+; Sr5; Sr11; Sr7a; Sr8a; Ppd-A1a; Ppd-B1a; Ppd-D1a; Ppd-B1a; Ppd-D1a; Kr1; Kr2; Rth2; Rht6; Rht2; Vrn1; Vrn2; Vrn3; d1; d2; d3; Ne1; Ne2; Ch1; Ch2; Ch1(ws); Ch2(ws); Ch3(ws); Yr2; Yr18?; Nor-B1a; Nor-B2a/Nor-B2b; Nor-B1e; Glu-A1a; Glu-B1i; Glu-D1d	2.6-3.5	Nov.15-30	Mar.-Apr.	1974
INIA 66	Inia 66	Lr2a; Lr13; Lr14a; Lr17; Lr23; Lr27; Lr34; Sr2; Sr8a; Sr8; Sr9a; Sr11+; Sr30; Ne1; Ne2; Ne2m; Vrn1; Vrn2; Vrn3; Rht1; YrA; Yr30; Ch1(ws); Ch2(ws); Ch3(ws)	2.5-3.8	Nov.15-30	Mar.-Apr.	1974
Norteno 67	Norteno67; NOR- 67	Vrn1; Vrn2; Vrn3; Ne1; Ne2w; Ne2; Ch1(ws); Ch2(ws); Ch3(ws); D1; D2; D3; Sr2; Sr8a; Sr30; Lr1; Lr2a; Lr2c; Lr13; Lr34; Ltn; Yr18; Bt10; Bdv1; Rht1	3.4-3.6	Nov.15-30	Mar.-Apr.	1974
Sonalika	SKA	Sr2; Sr11; Sr6; Sr7b; Sr8a; YrA; Yr2; Yr8; Yr15; non-Yr8; non-Trl; Lr1; Lr2a/Lr2b/Lr2c/Lr2d; lr3(do)/lr3(ba); Lr9; Lr10; Lr11; Lr12; Lr13; Lr13+; Lr14a/Lr14b; Lr15; Lr16; Lr17; Lr18; Lr19; Lr20; Lr21; Lr22+; Lr27; d1; d2; d3; Ch1; Ch1(ws); Ch2(ws); Ch2m; Ch2; Ch3(ws); Ne1; Ne2; Ne2m; Ne2s; Rht1; Rht-B1a; Rht-D1b; Rht2; Vrn1; Vrn2; Vrn3; Kr1; Kr2	2.5-3.3	Nov.15-30	Mar.-Apr.	1974
Nuri 70	Nuri; Nuri-F-70; Nuri70; Nuri-70; Nuri F-70	Rht2; Sr2; Sr5; Sr6; Sr8a; Sr10; Sr17; YrA; Yr6; Yr8; Ne2; Lr1; Lr10; Lr13; Lr14a; Lr27; Lr34+;	2.5-3.6	Nov.15-30	Mar.-Apr.	1975
Jupateco 73	Jupateco F-73; Jupateco F 73; Jupateco-73; JUP	Lr2?; Lr3; Lr12; Lr13; Lr14a; Lr17; Lr27; Lr31; Lr34; Yr18; Sr2; Sr6; Sr8a; Sr30; Rht1; Rht2; Rht8a; Vrn1; Vrn2; Vrn3	3.6-3.8	Nov.15-30	Mar.-Apr.	1975
Tonori 71	TANORI-71; Tanori F-71; Tanori F71; Tonori 71;	Rht1; Ne1; Ne2; Lr1; Lr17; Lr13	3.6-3.8	Nov.15-30	Mar.-Apr.	1975
Balaka	-	-	2.6-3.9	Nov.15-30	Mar.-Apr.	1979
Doel	-	-	2.5-3.5	Nov.15-30	Mar.-Apr.	1979
Pavon 76	Pavon76; Pavon-76; PAVON-F-76; Pavon 76-BGD; PVN-B	Lr1; Lr10; Lr13; Lr46; Lr2b; Lr14a; Lr22a/Lr22b; Lr27; Sr8a; Sr9g; Sr11; Sr30; Sr2; Sr8a; Sr9g; Sr30; Yr6; Yr7; Yr2; Yr8; Yr29; Yr30; non-Yr8; Ne2; Rht2; T1BL.1RS; non-1RS; non-Trl; Vrn1; Vrn2; Vrn3; Bls1; Bls2	3.2-4.2	Nov.15-30	Mar.-Apr.	1979
Ananda	BAW 18	Rht1	2.1-3.4	Nov.15-30	Mar.-Apr.	1983
Kanchan	BAW 28	Rht2; Lr13	2.6-4.5	Nov.15-30	Mar.-Apr.	1983
Akbar	BAW 43	-	2.5-4.2	Nov.15-30	Mar.-Apr.	1983
Barkat	BAW 39	-	2.5-3.5	Nov.15-30	Mar.-Apr.	1983
SERI 82-BGD	-	-	2.5-3.6	Nov.15-30	Mar.-Apr.	1987
Aghrani	BAW 38	-	2.5-3.6	Nov.15-30	Mar.-Apr.	1987
PAK81	-	-	2.5-3.6	Nov.15-30	Mar.-Apr.	1988
Sawgat	BARI Gom 17 Sawghat	Lr13; Lr23	2.7-3.7	Nov.15-30	Mar.-Apr.	1993
Prativa	BARI Gom 18]	-	2.8-3.8	Nov.15-30	Mar.-Apr.	1993

Table 7. Existing wheat variety of Bangladesh developed since 1998 to 2012 (Sources: BARI, 2013; CIMMYT, 2013; Hossain and Teixeira da Silva, 2013)

Variety	Synonym	Stress tolerance capacity	Variety type	Life duration (days)	Yield (t ha^{-1})	Year of release	Sowing time	Harvest time	Major diseases and pests
Sourav	BARI Gom 19	Moderately heat tolerant	Spring, semi-dwarf	102-110	3.5-4.5	1998	Nov.15-30	Mar.-Apr.	Tolerant to *Bipolaris* leaf blight and resistant to leaf rust
Gourab	BARI Gom 20	Heat sensitive	Spring, semi-dwarf	102-108 leaf	3.5-4.6	1998	Nov.15-30	Mar.-Apr.	Tolerant to *Bipolaris* blight and resistant to leaf rust
Shatabdi	BARI Gom 21	Good level of tolerance to terminal heat	Spring, semi-dwarf	105-110	3.6-5.0	2000	Nov.15-30	Mar.-Apr.	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust
Sufi	BARI Gom 22	Tolerant to late heat stress	Spring, semi-dwarf	105-110	3.6-5.0	2005	Nov.15-30	Mar.-Apr.	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust
Bijoy	BARI Gom 23	Moderately heat tolerant	Spring, semi-dwarf	103-112	4.3-5.0	2005	Nov.15-30	Mar.-Apr.	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust
Prodip	BARI Gom 24	High yielding, but heat sensitive	Spring, semi-dwarf	102-110	4.3-5.1	2005	Nov.15-30	Mar.-Apr.	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust
Tista	BARI Gom 25	Moderate level of tolerance to heat stress	Spring, semi-dwarf	102-110	3.6-5.0	2010	Nov.15-30	Mar.-Apr.	Highly tolerant to *Bipolaris* leaf blight and resistant to leaf rust
Hashi	BARI Gom 26	Tolerant to terminal heat stress in late seeding	Spring, semi-dwarf	104-110	3.5-5.0	2010	Nov.15-30	Mar.-Apr.	Tolerant to *bipolaris* leaf blight and resis-tant to leaf rust (stem rust) race Ug 99
Francolin	BARI Gom 27	Moderate level of tolerance to heat stress	Spring, semi-dwarf	105-110	3.8-5.4	2012	Nov.15-30	Mar.-Apr.	It is resistant to leaf rust and tolerant to *Bipolaris* leaf blight and possesses good level of APR to the Ug99 race of stem rust and its variants
BARI Gom 28	BARI Gom 28	Tolerant to terminal heat stress in late seeding	Spring, semi-dwarf	100-105	4.0-5.5	2012	Nov.15-30	Mar.-Apr.	It is resistant to leaf rust and tolerant to *Bipolaris* leaf blight

N.B. Genetic information for these varieties is available in another review (Hossain and Teixeira da Silva, 2013)

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